

The Mineralogy of the 4 MSL Landing Sites



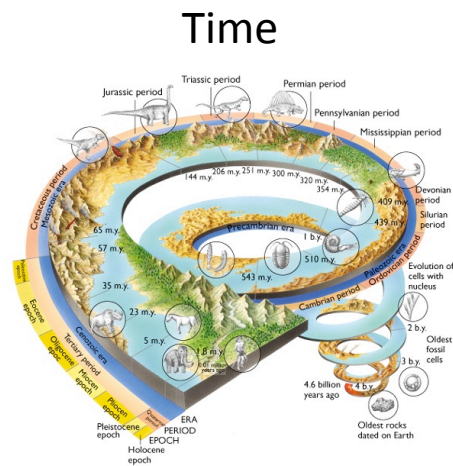
Ralph Milliken
University of Notre Dame

Not All Clays are Created Equal: Why Care About Mixed-Layered Clays?

Clay minerals have been suggested to be important for the origin of life and preservation of organic material: they will be a prime target of the MSL rover and likely Mars Sample Return.

Mixed-layered clays contain chlorite or illite interlayers and are a common product of diagenesis, thus they may indicate a reduced potential for preservation of organic material (indicate later interaction with fluids, increased temperature).

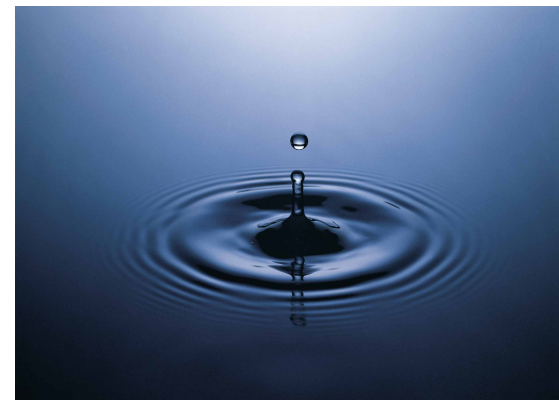
Presence of mixed-layered clays may indicate several things about the geologic history of rocks:



Temperature



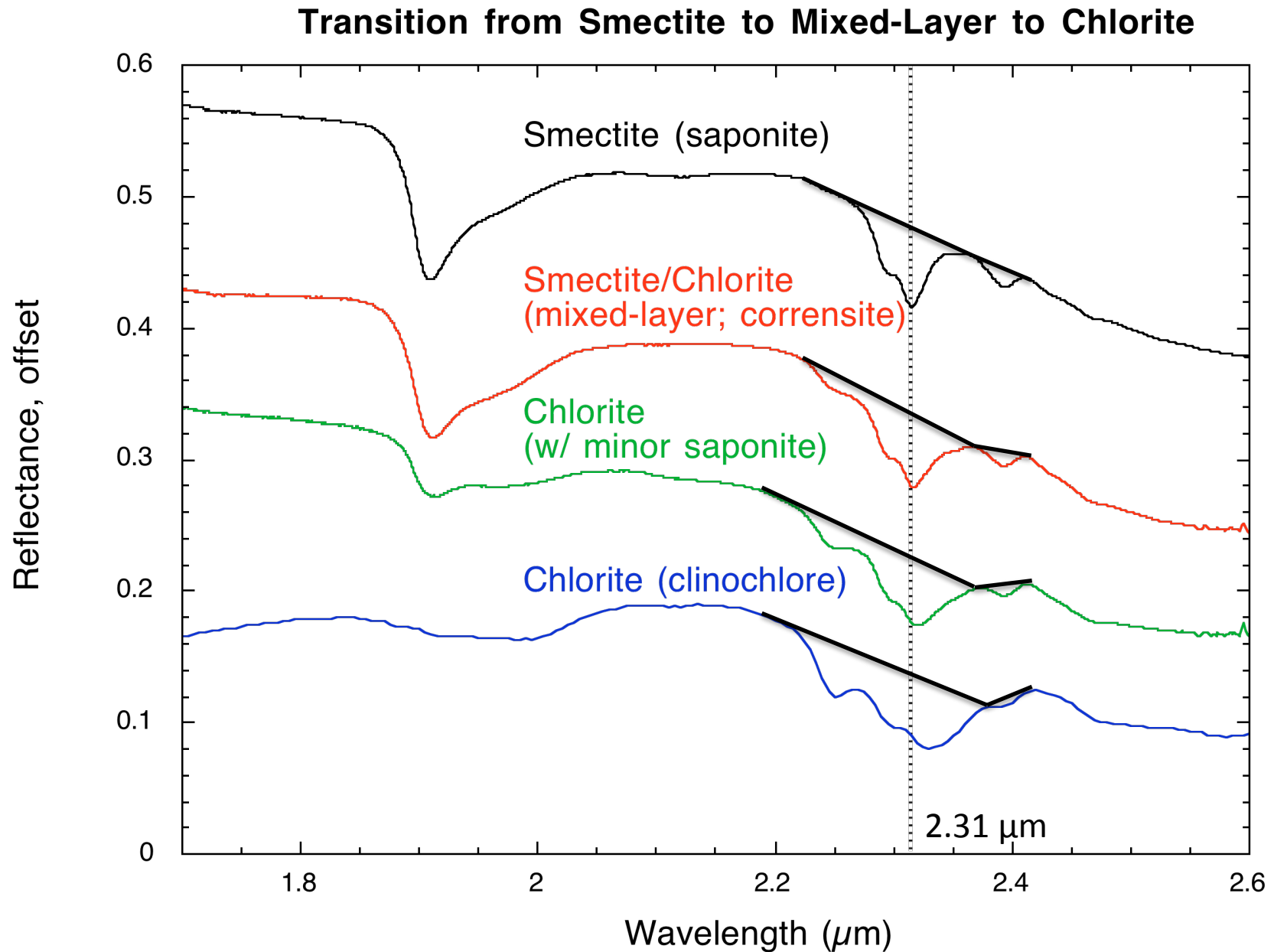
Fluids



Understanding the lateral and vertical distribution of clays in the ancient crust can tell us about fluid pathways, fluid chemistry, and local or regional heat flux. Certain types of mixed-layered clays (e.g., rectorite) are commonly associated with hydrothermal systems.

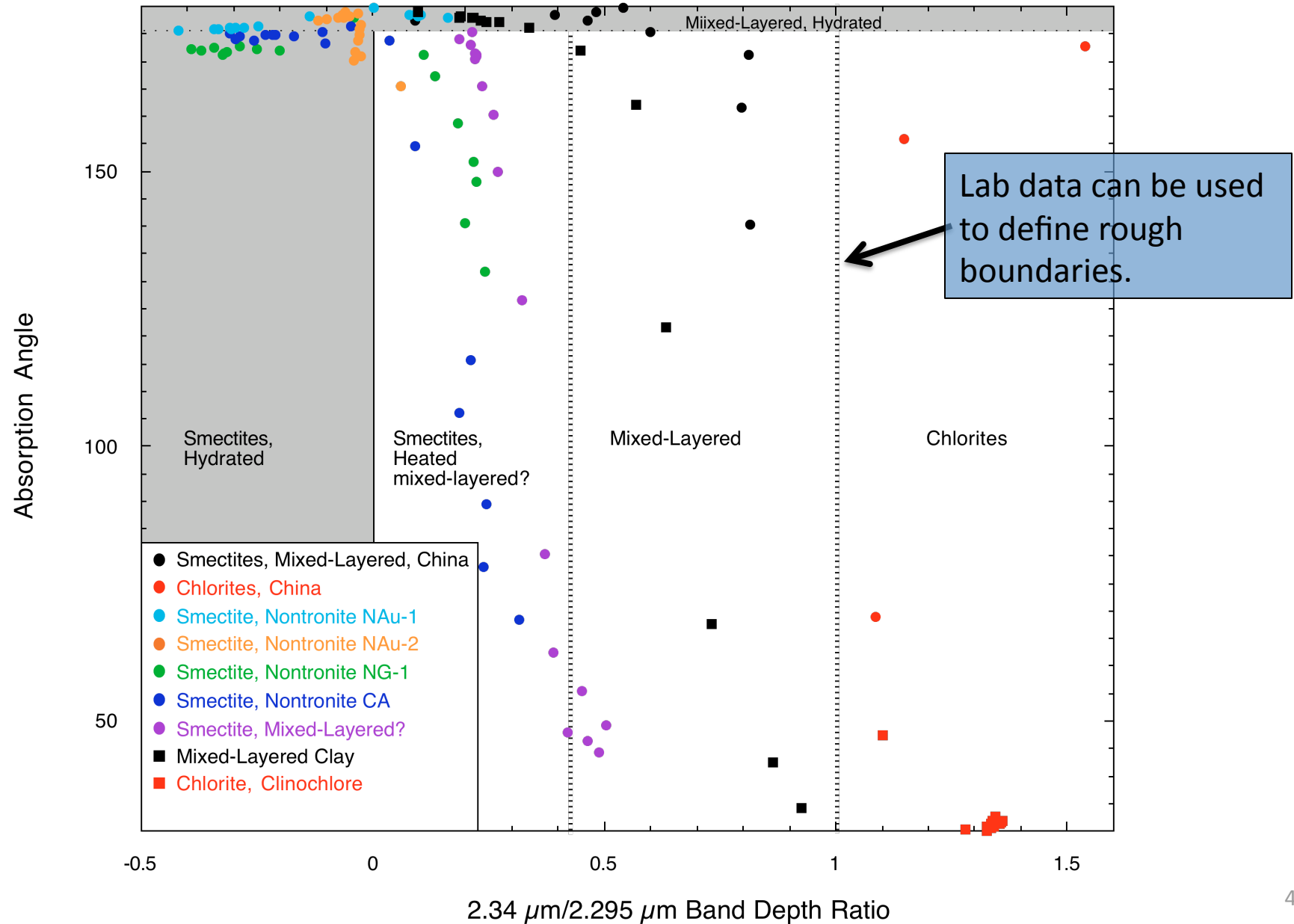
Were clays formed at the surface and buried, or were they formed in the subsurface?

Spectral Parameters for Mixed-Layered Clays: S-C/S-C Series, China

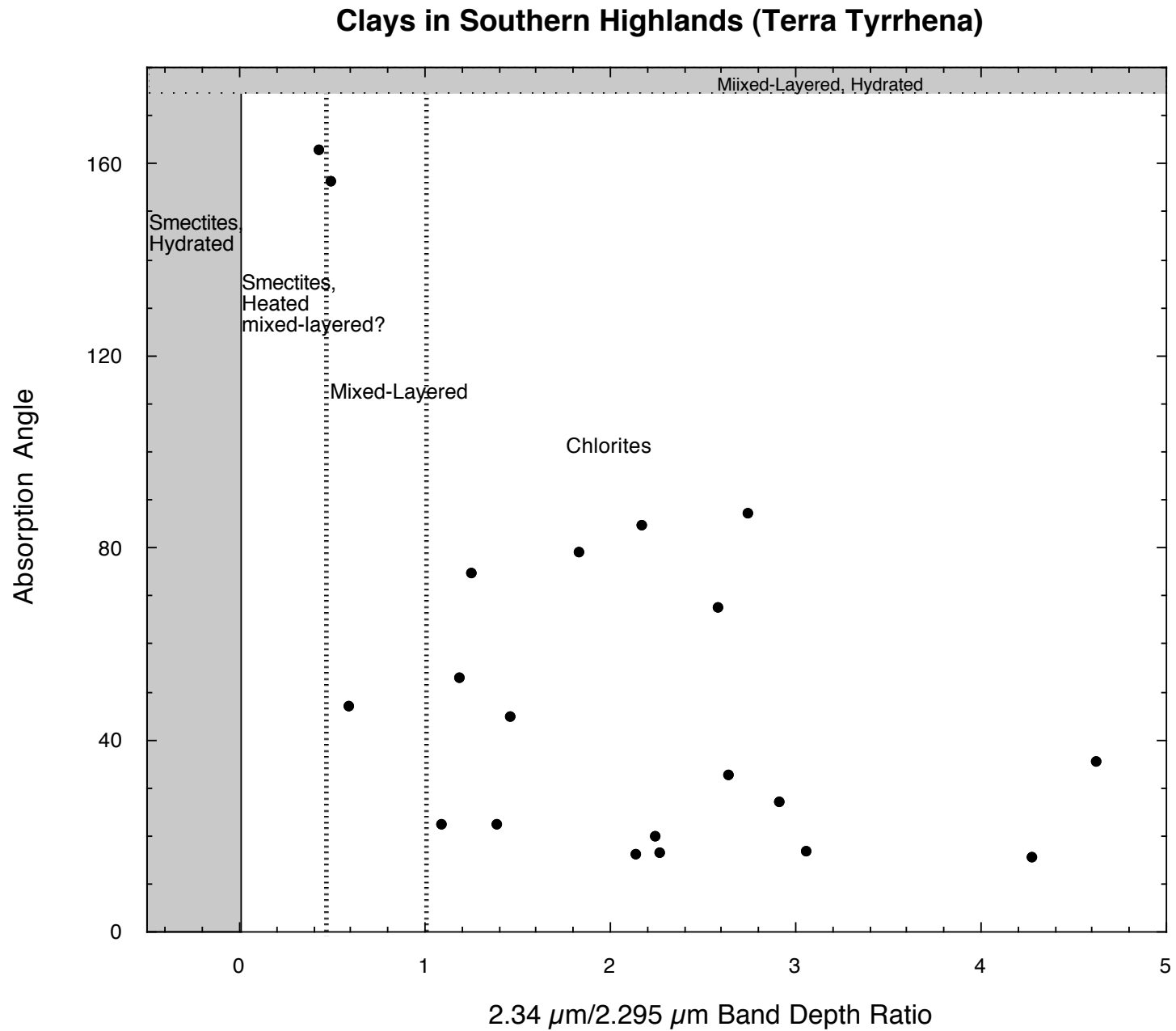


Trends Confirmed with Other Data for Various Hydration/Heating States

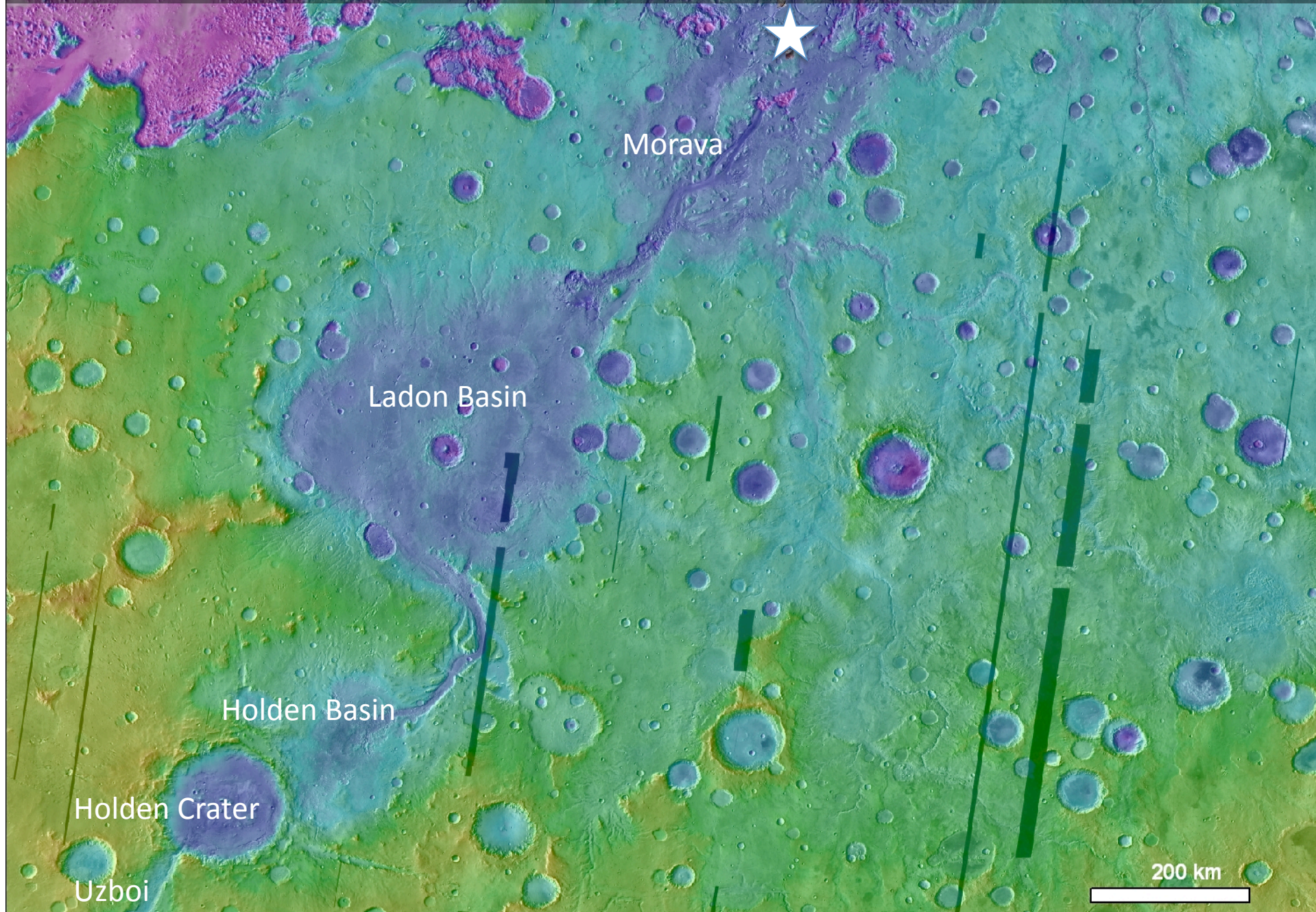
Spectral Parameterization of Clays



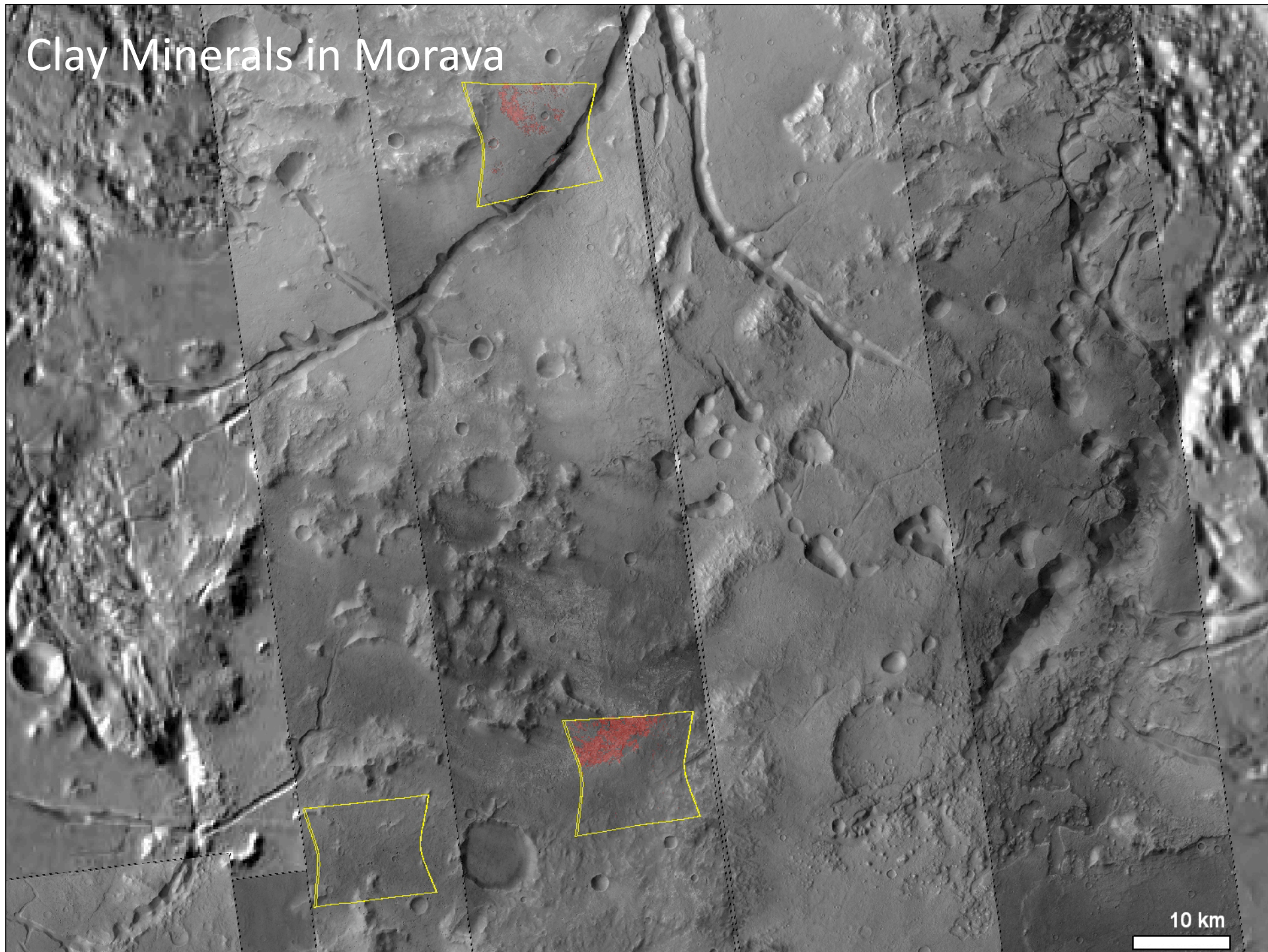
Southern Highlands: Dominated by Mixed-Layered C/S & Chlorite?



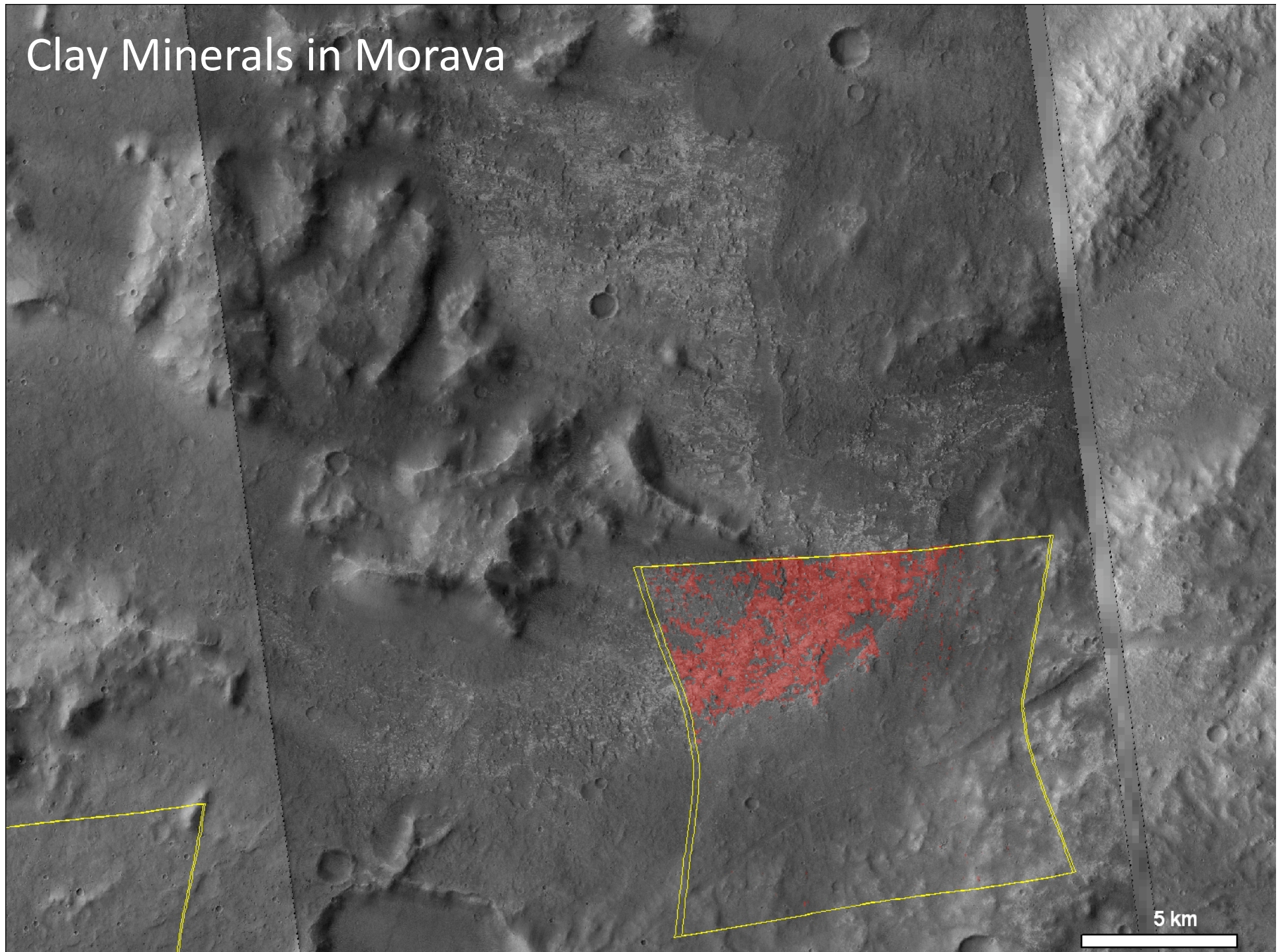
Clay Minerals in Uzboi-Ladon-Morava (ULM) System

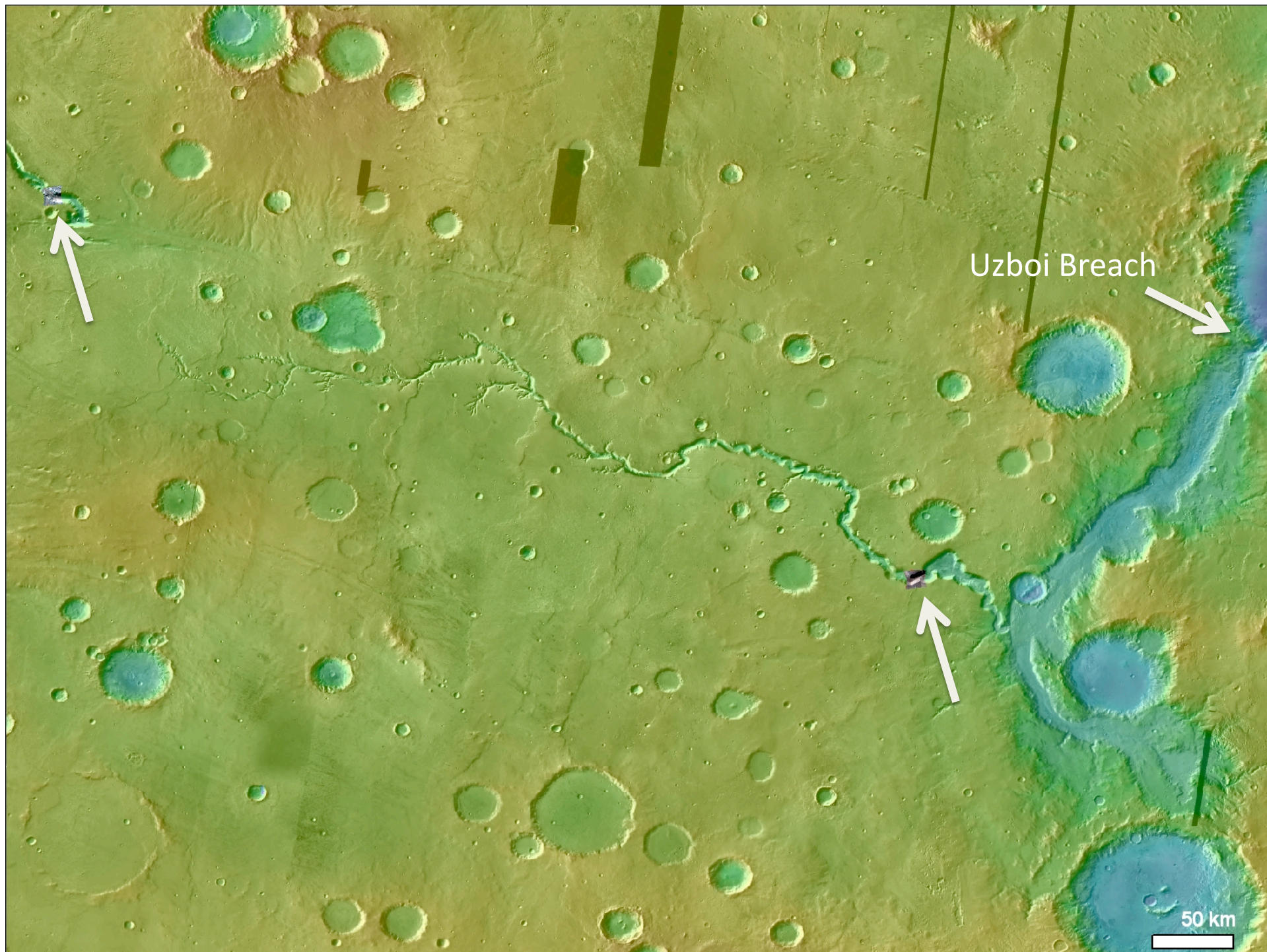


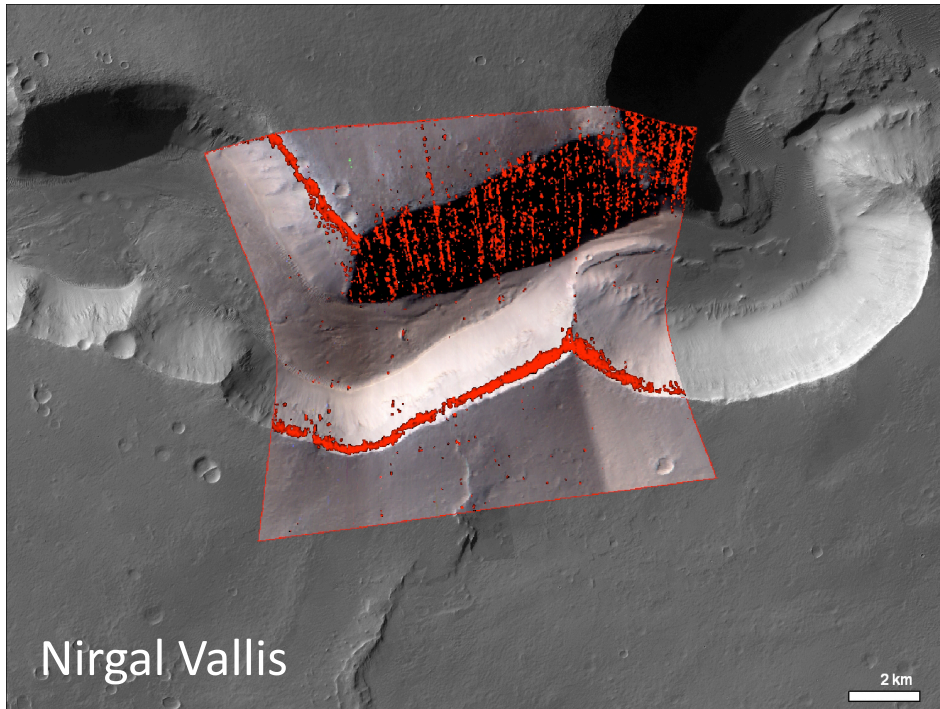
Clay Minerals in Morava



Clay Minerals in Morava

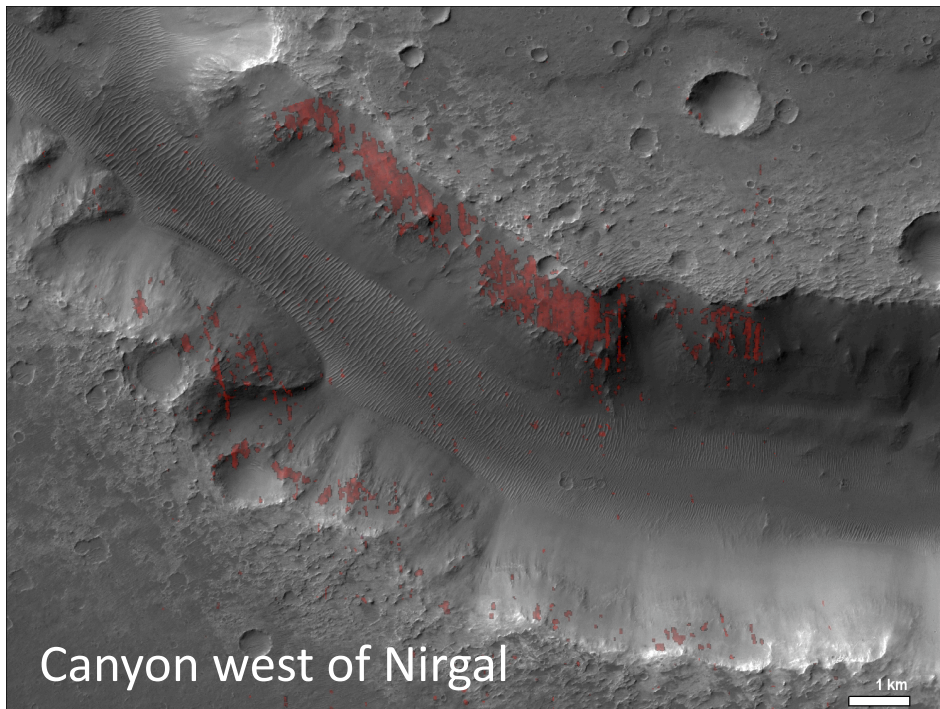






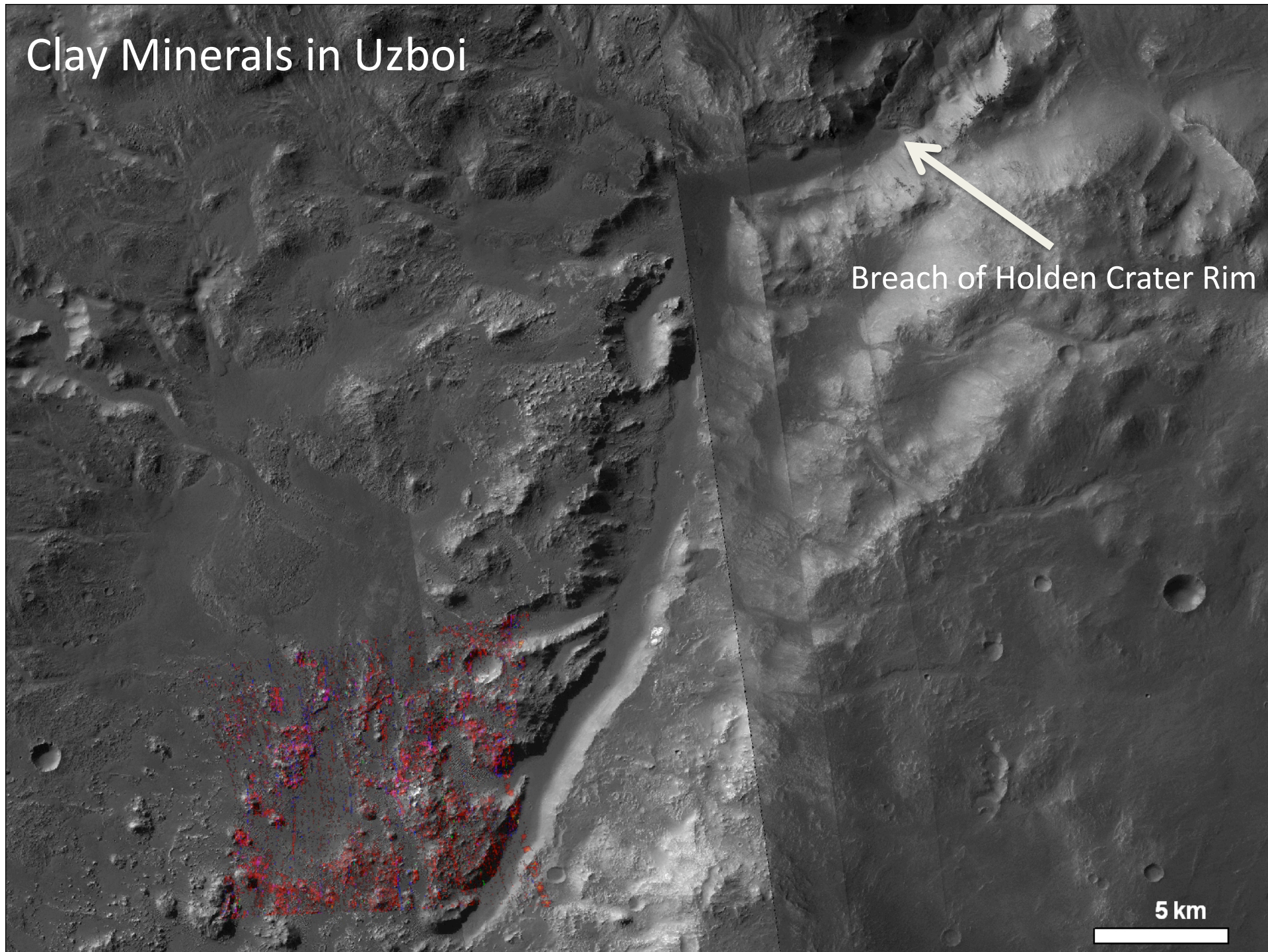
Strong clay mineral signature in near-surface strata exposed in Nirgal and plains surrounding ULM system.

This will be discussed in more detail by Debra Buczowski & Kim Seelos on Tuesday.



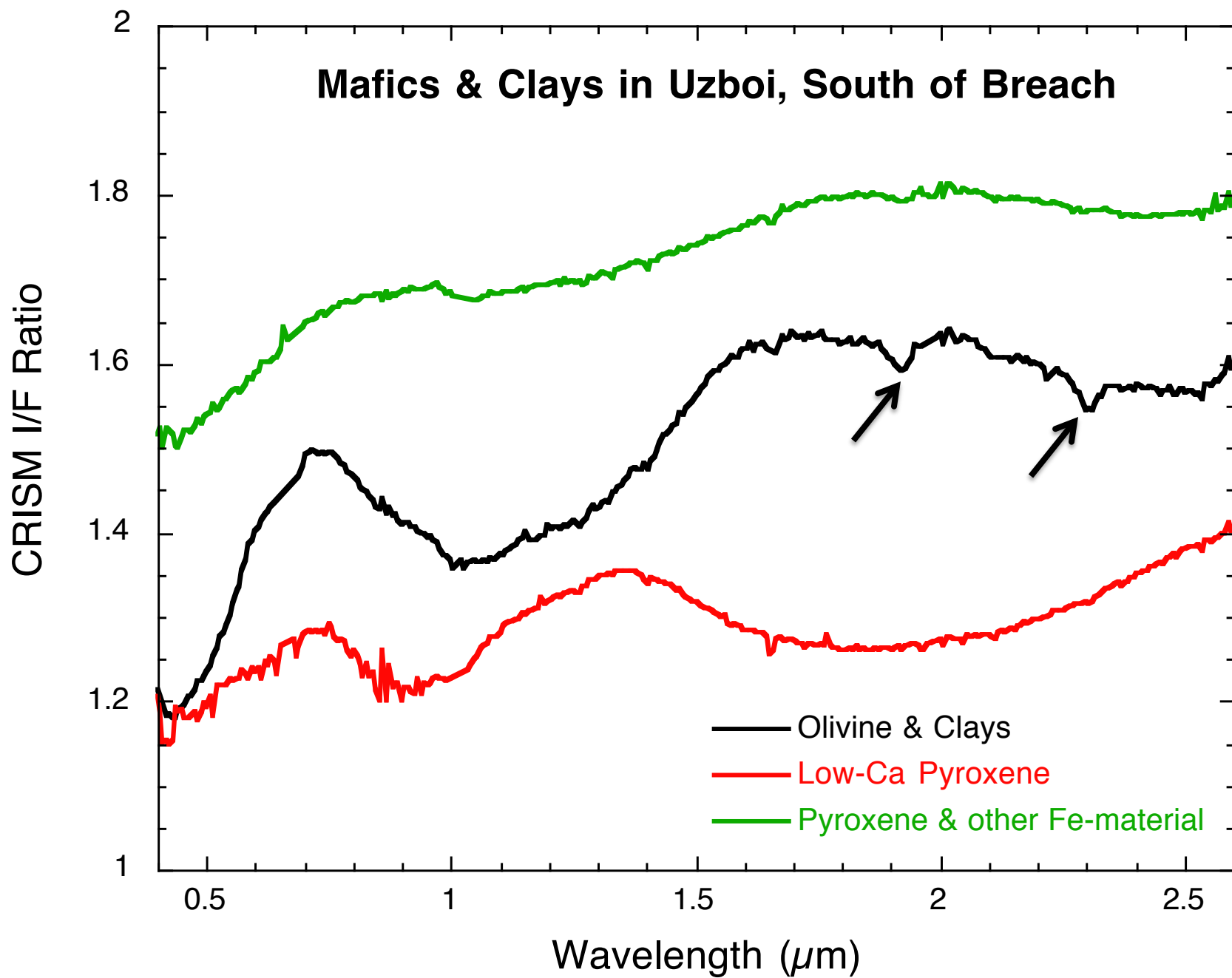
These clay signatures are very strong and are consistent with mixed-layered chlorite/smectite, similar to clays in ULM system.

Clay Minerals in Uzboi

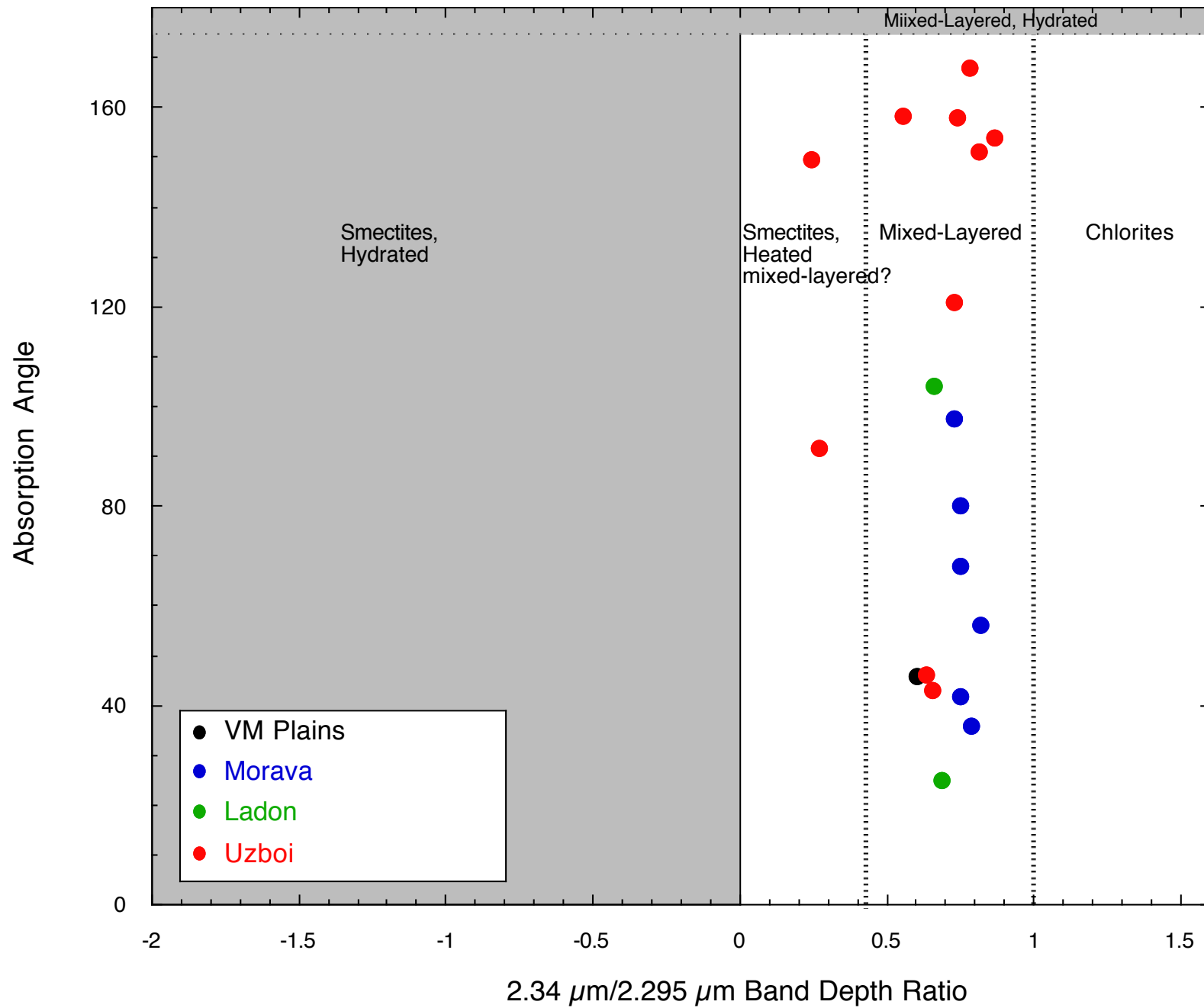


Breach of Holden Crater Rim

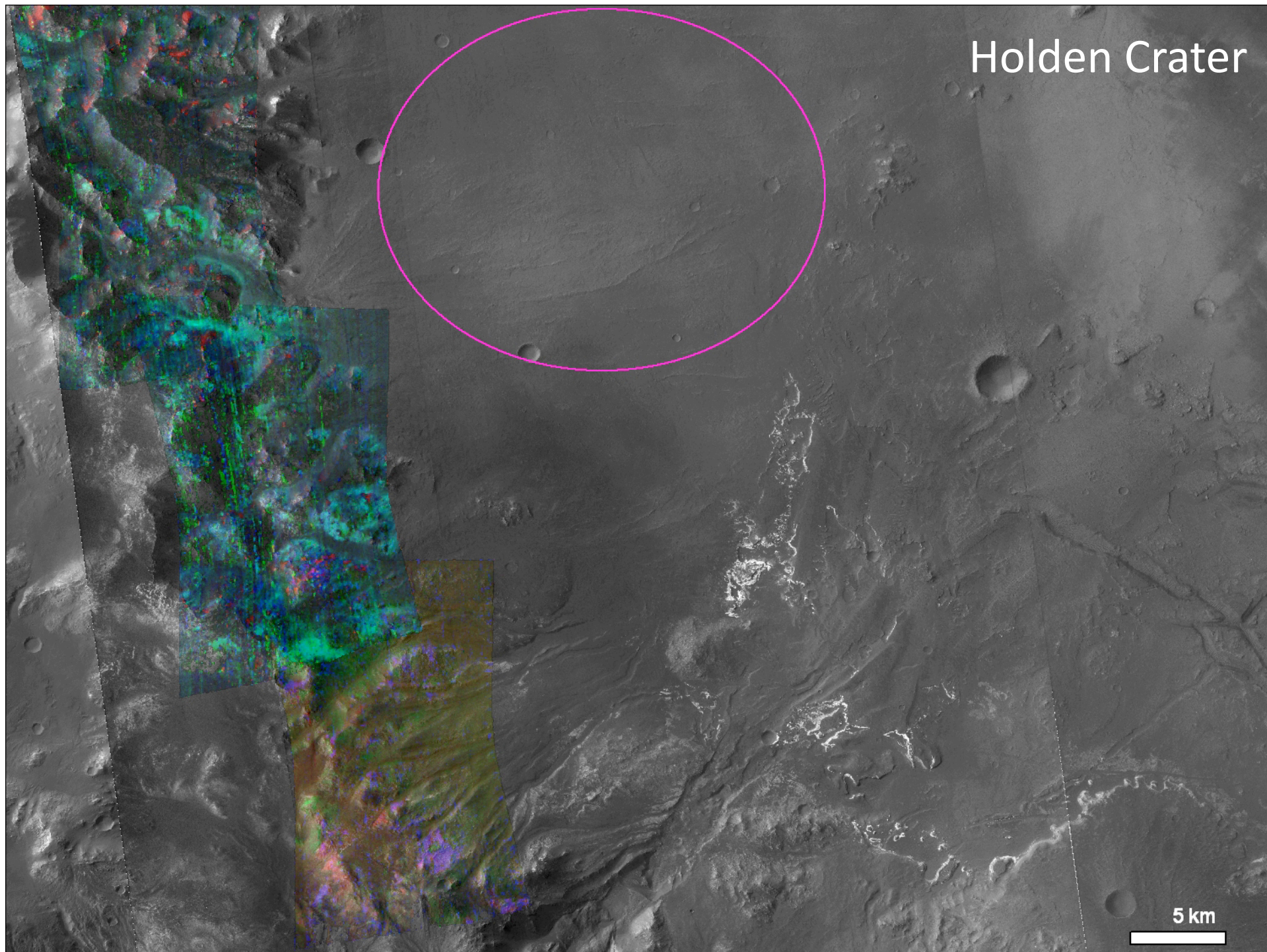
5 km

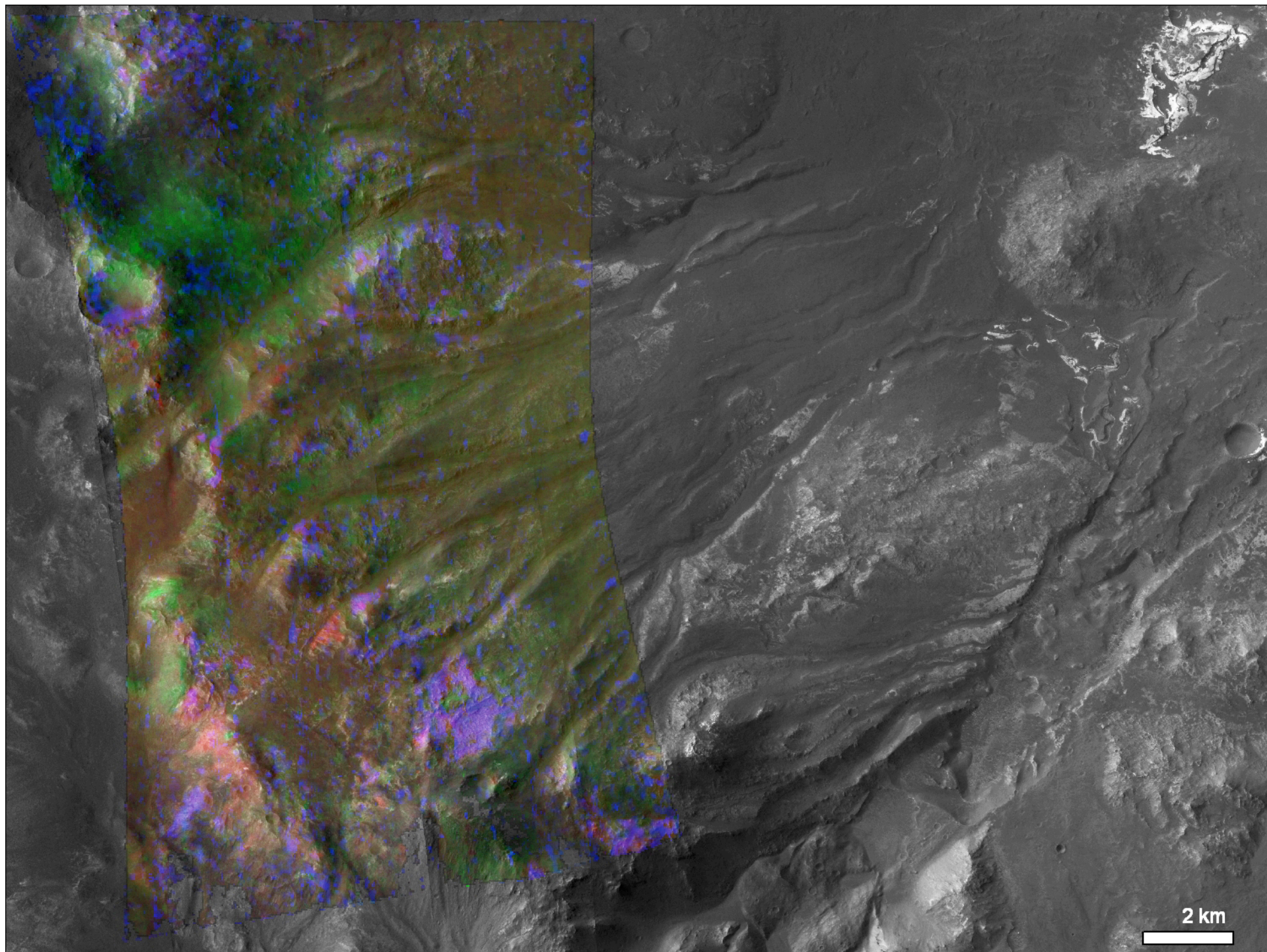


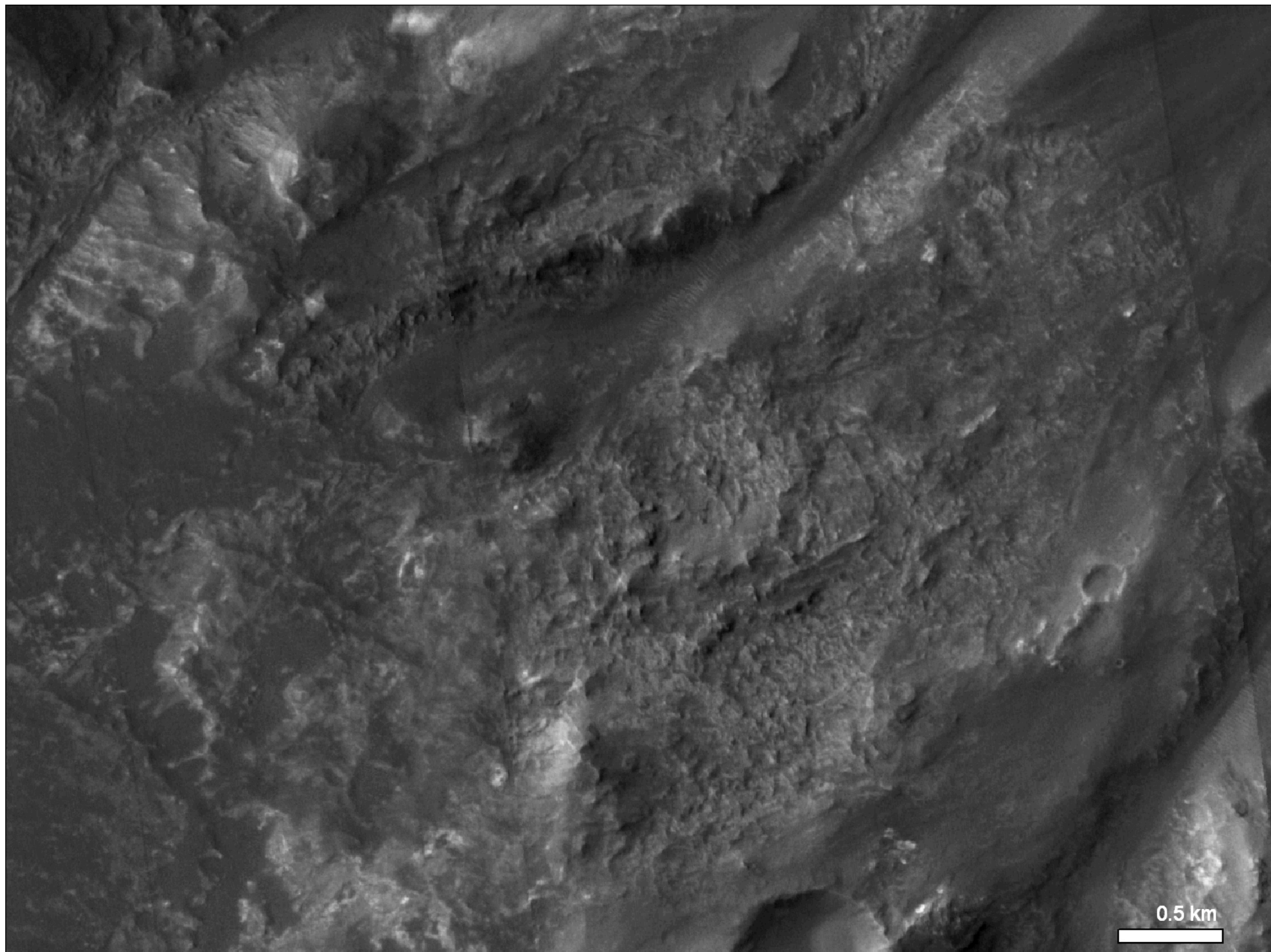
Valle Marineris Plains & ULM System

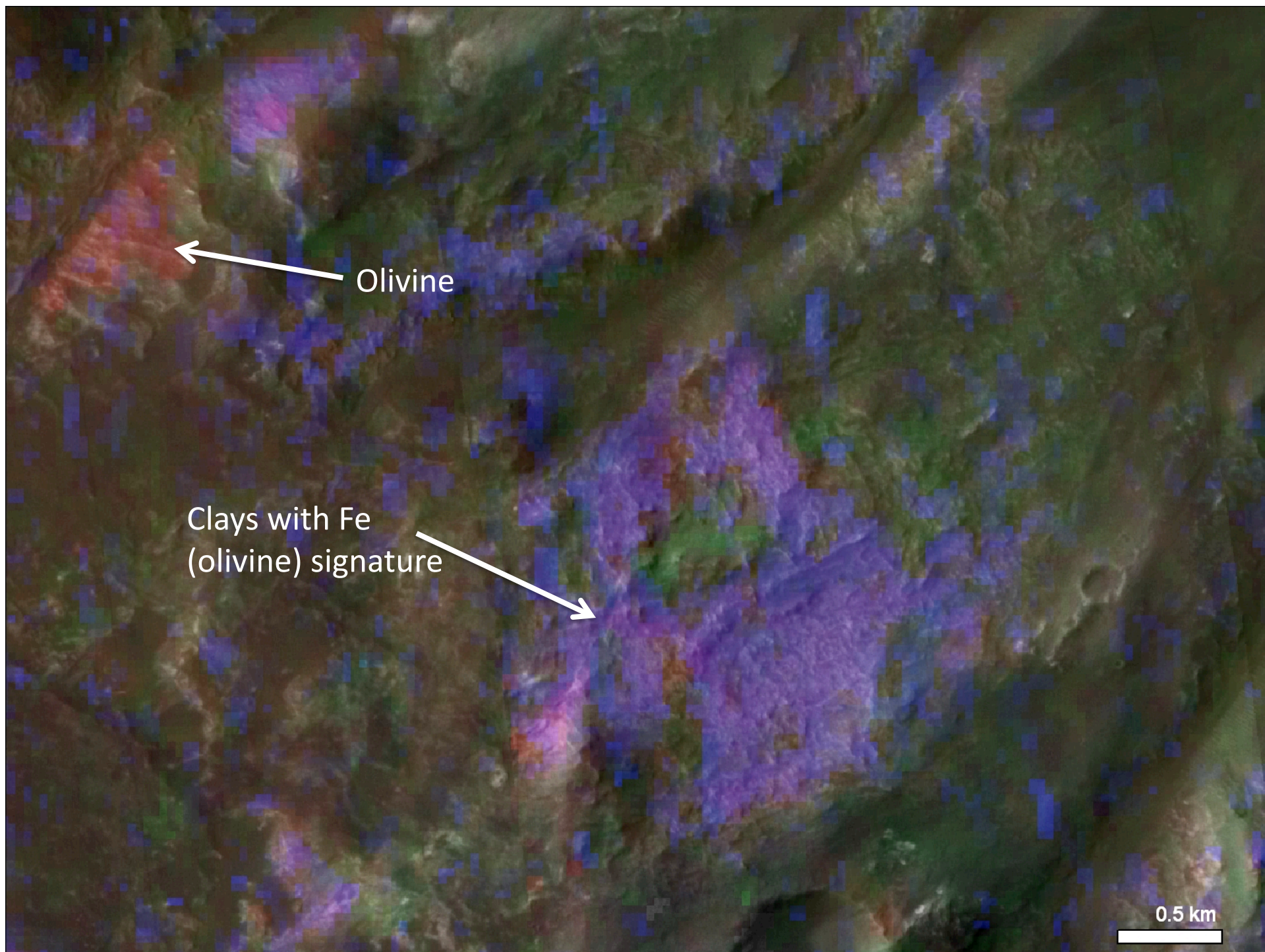


Holden Crater



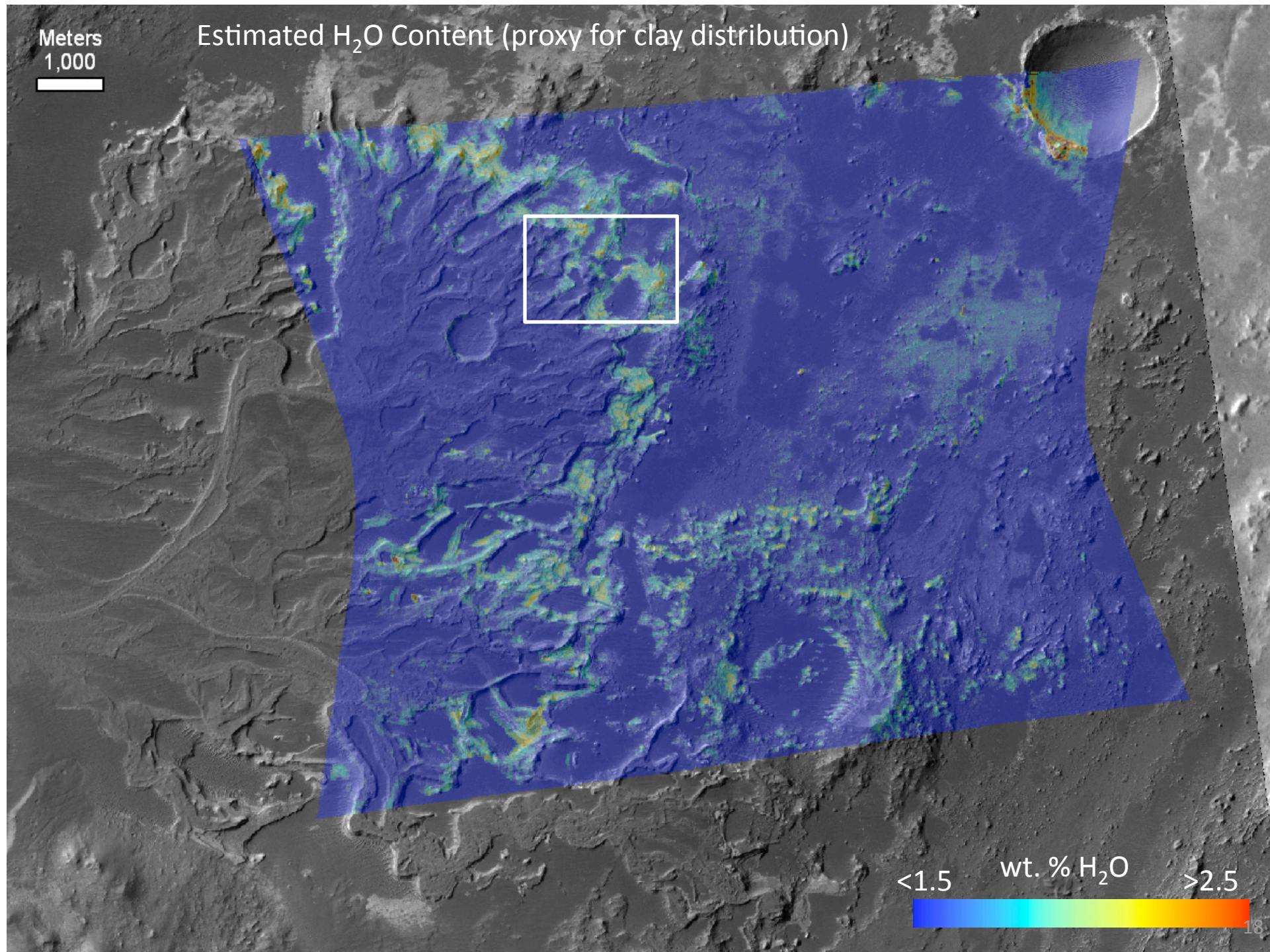


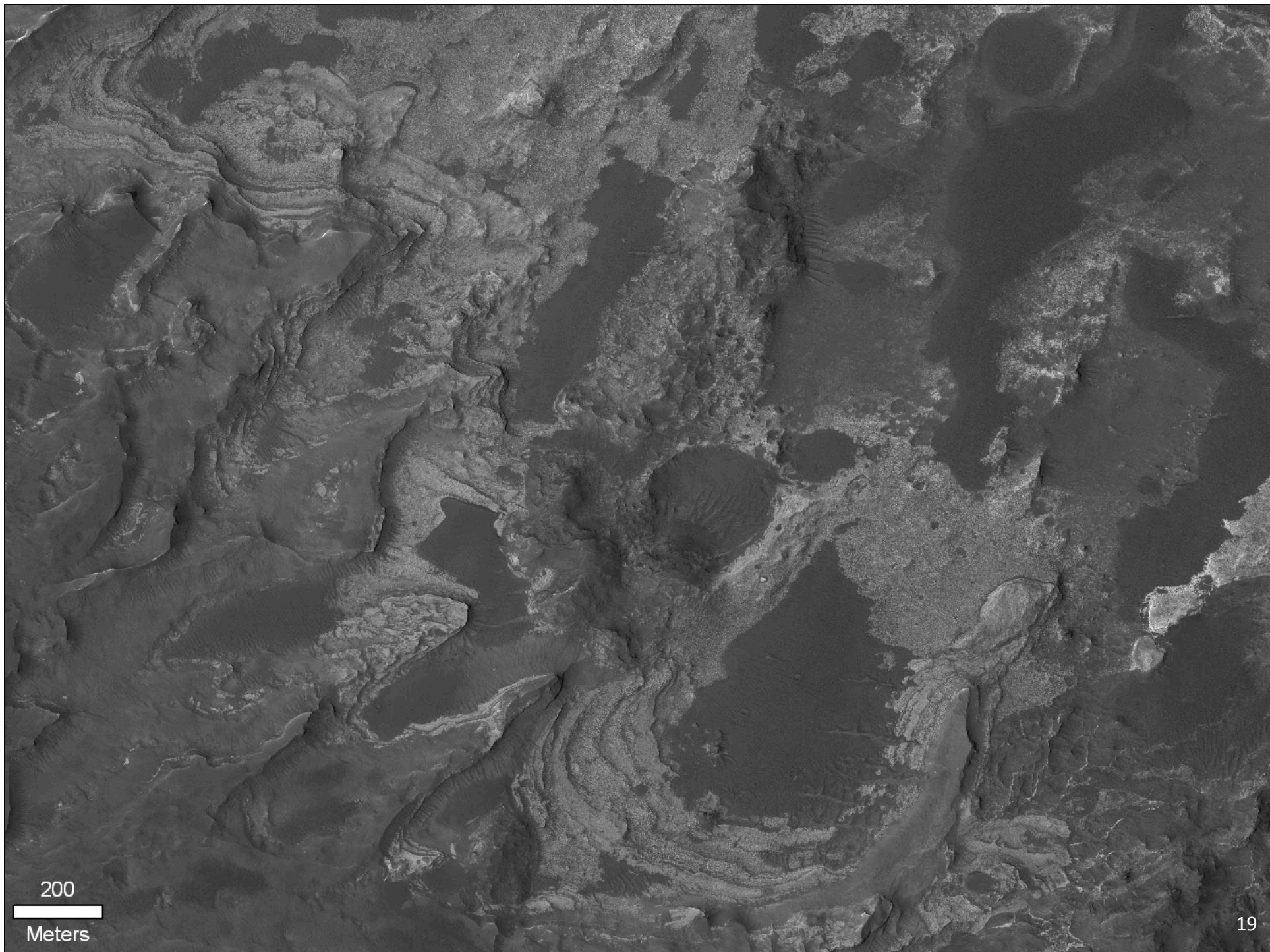


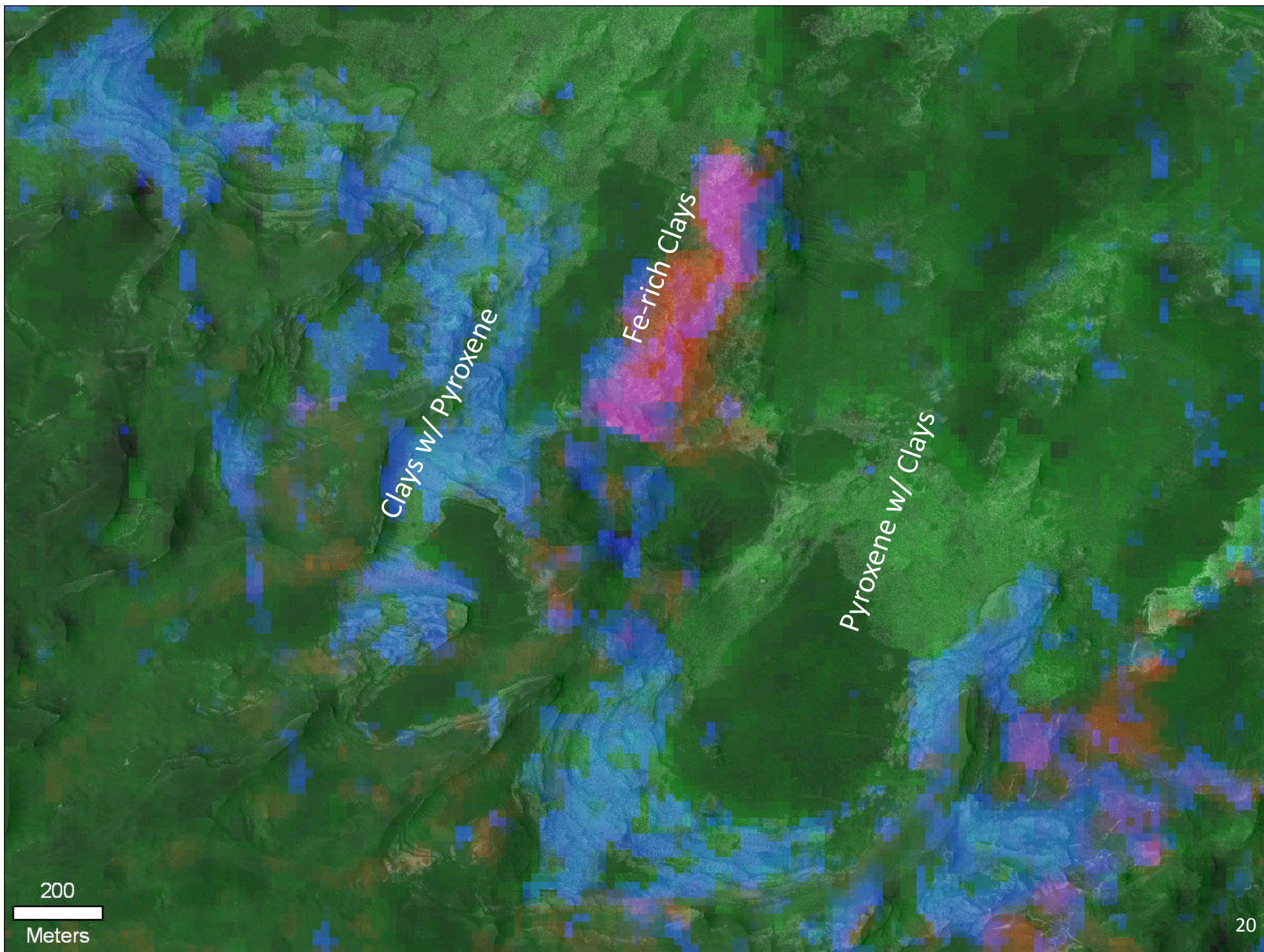


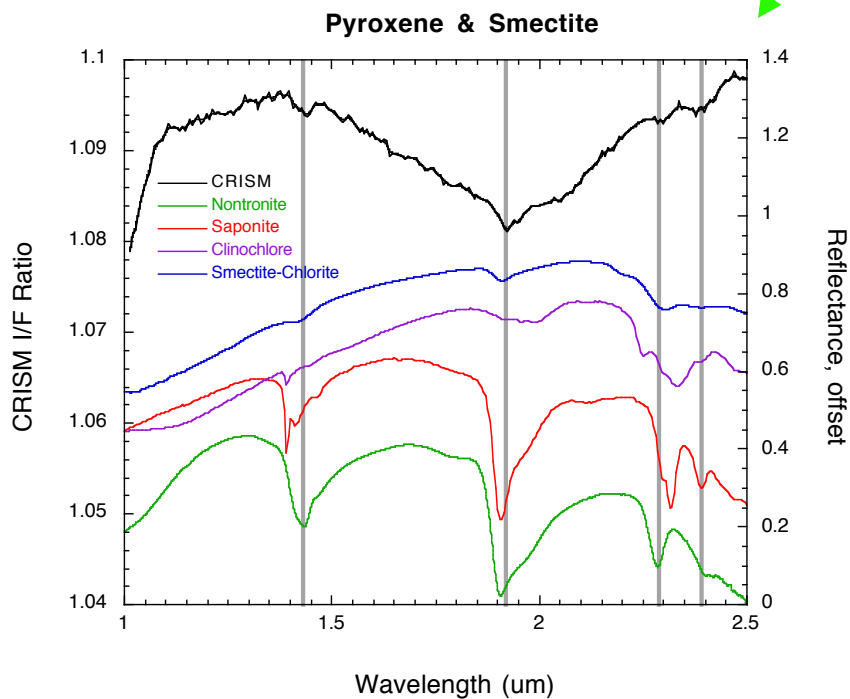
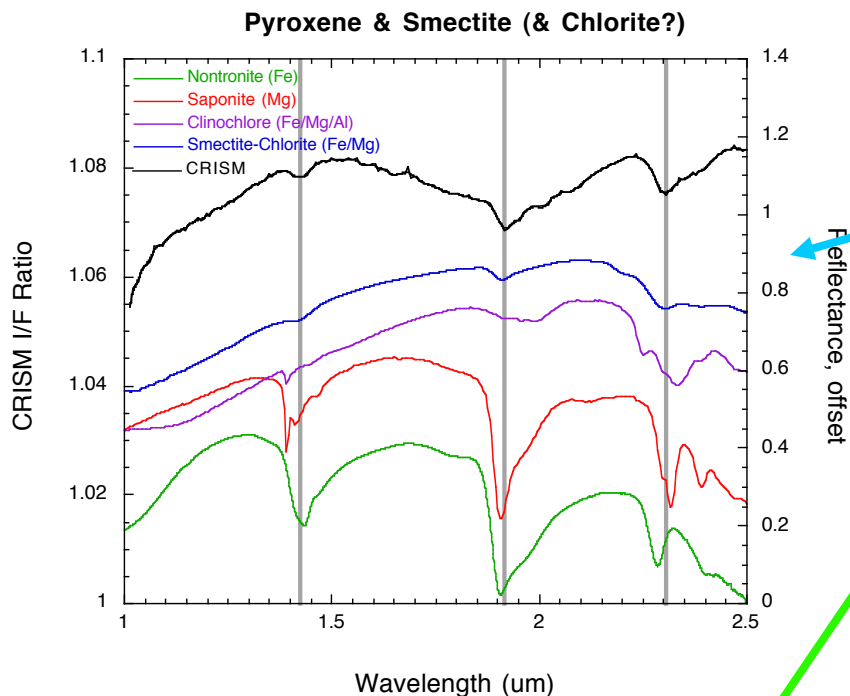
Meters
1,000

Estimated H₂O Content (proxy for clay distribution)



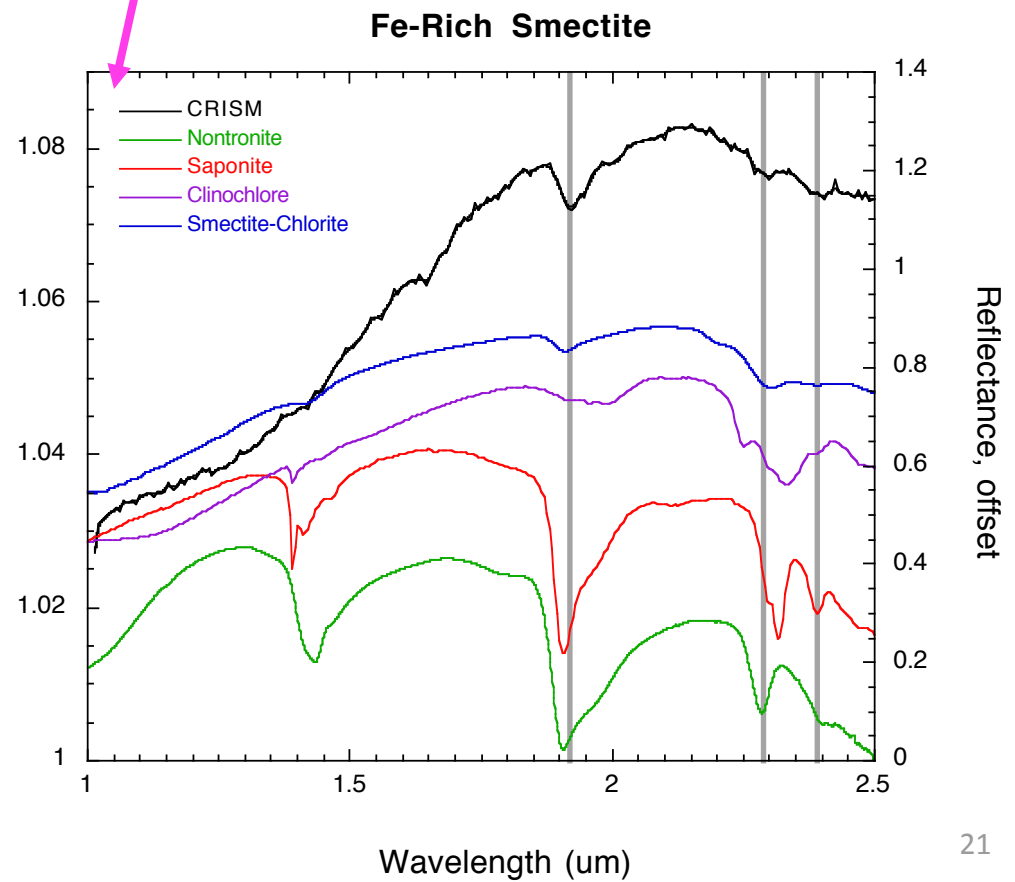




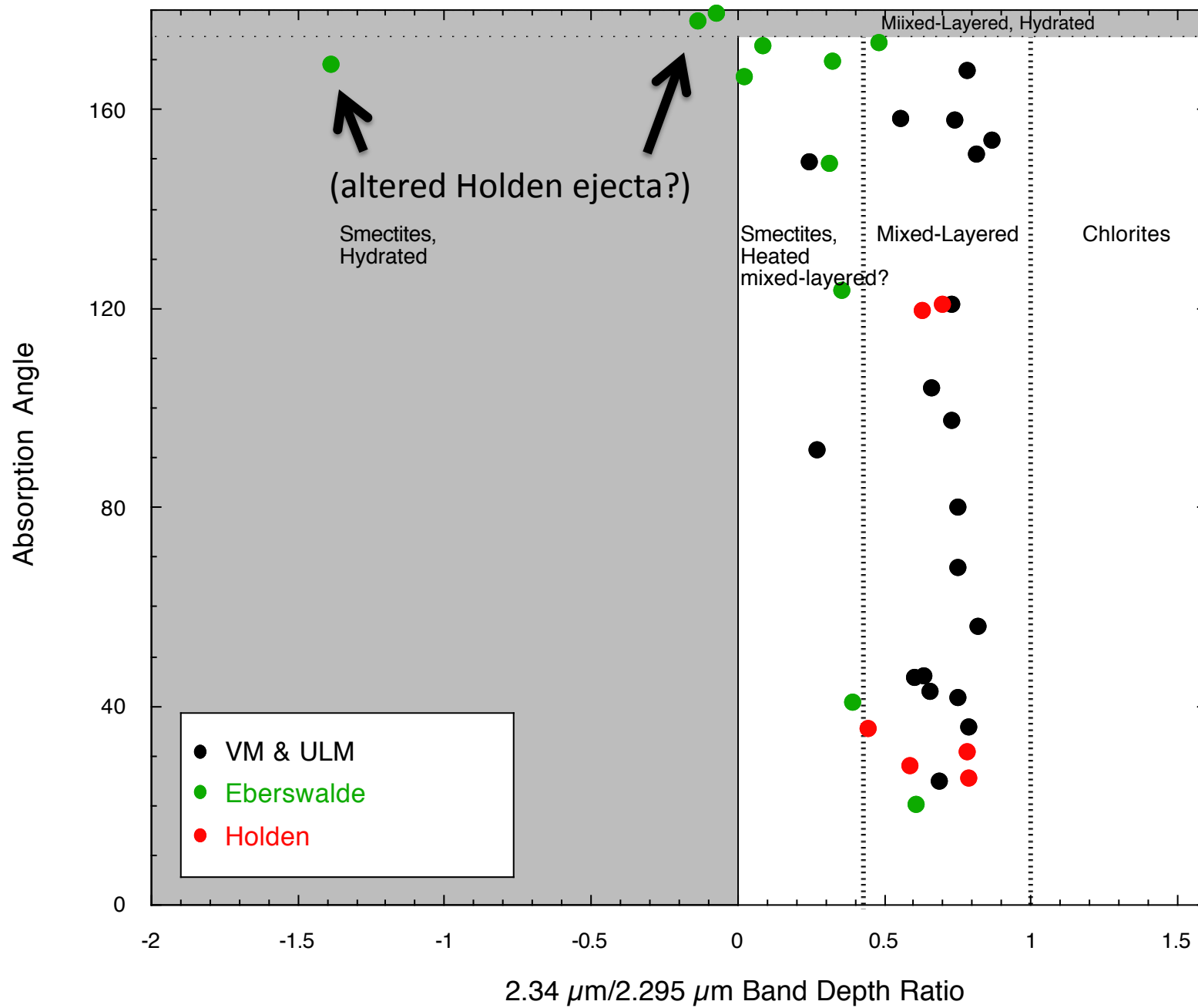


There are at least 3 distinct units:

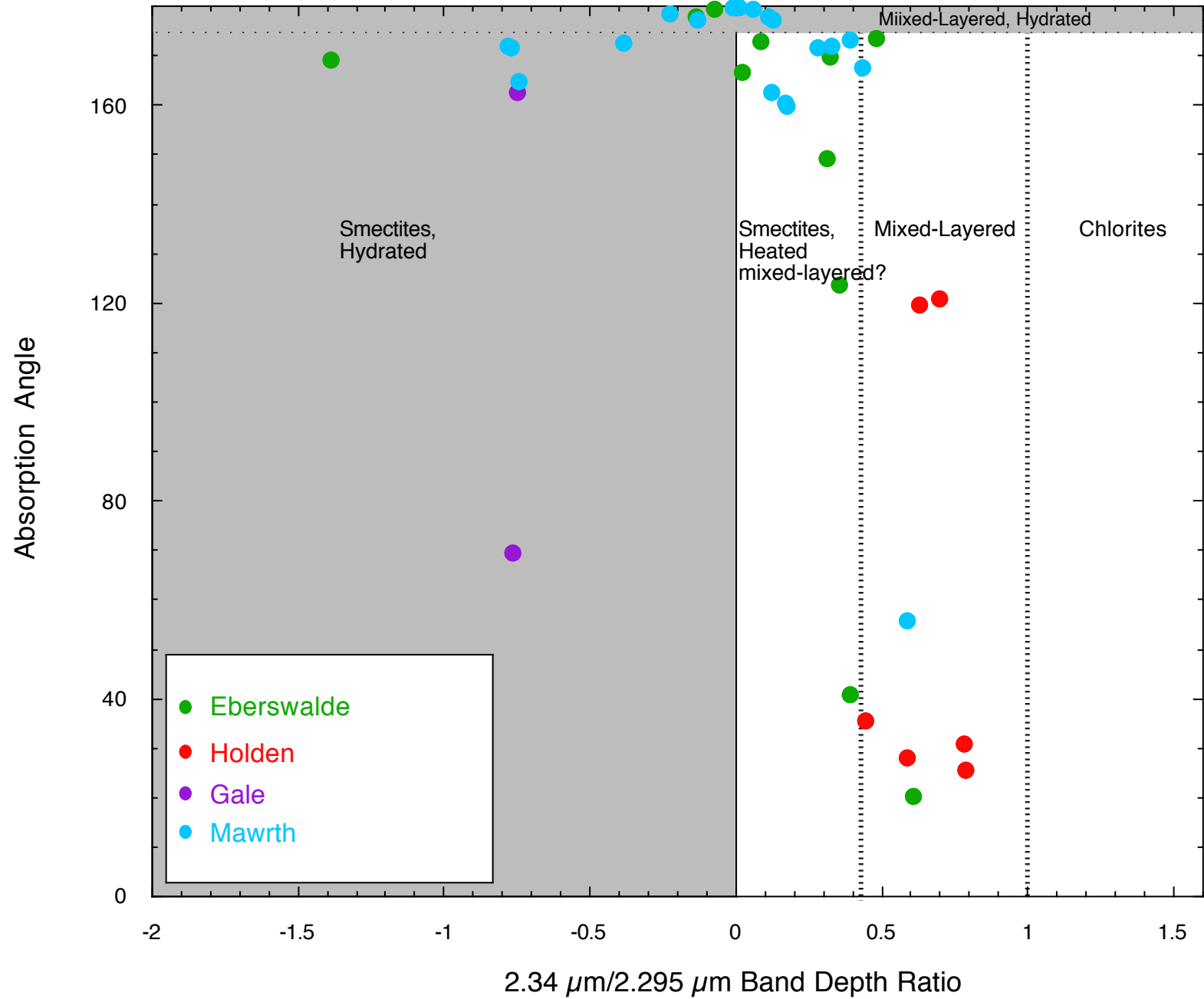
- Clay-bearing unit with pyroxene
- Pyroxene unit with clays
- Fe-rich clay unit



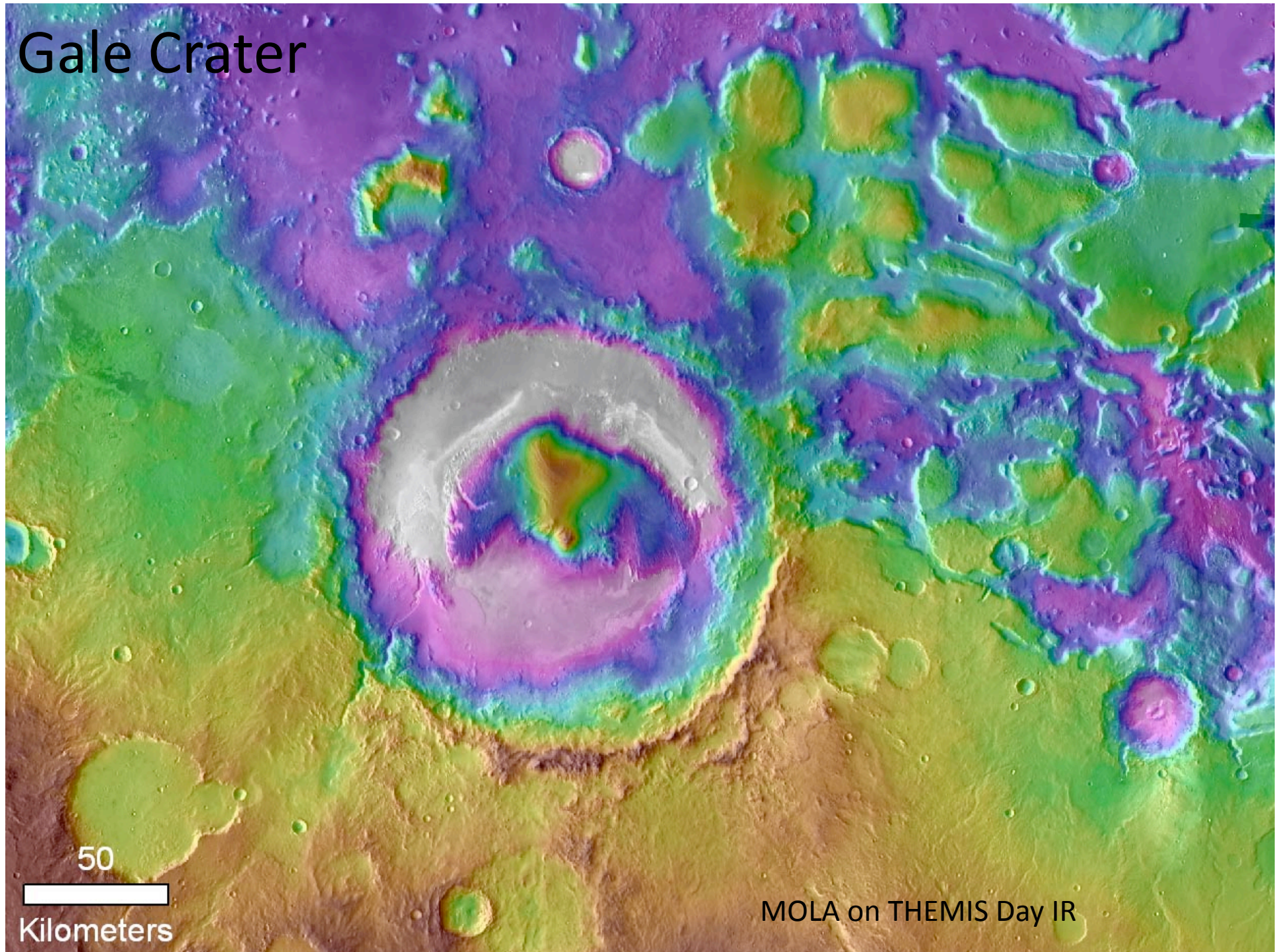
ULM, Holden, & Eberswalde



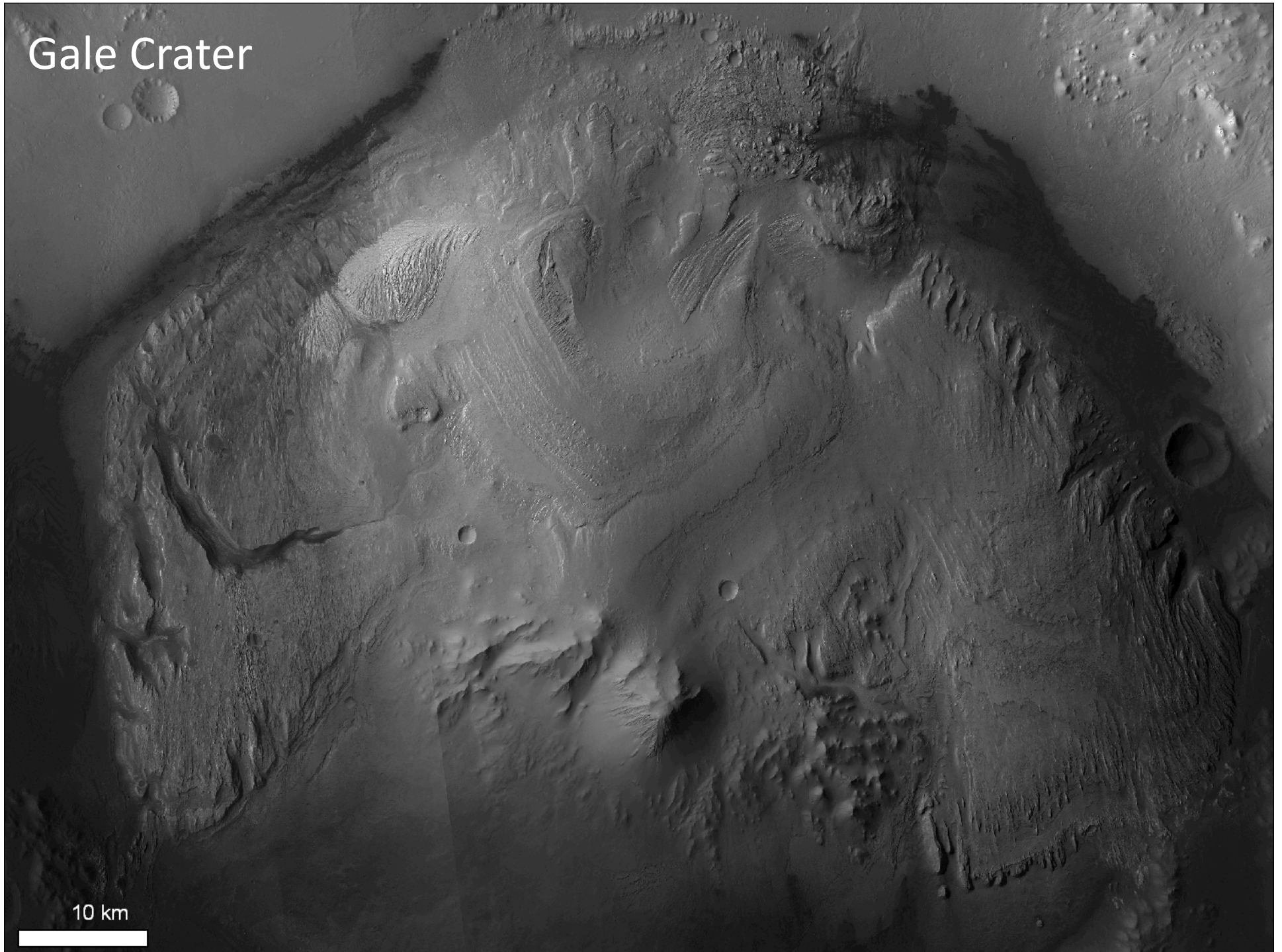
MSL Landing Sites

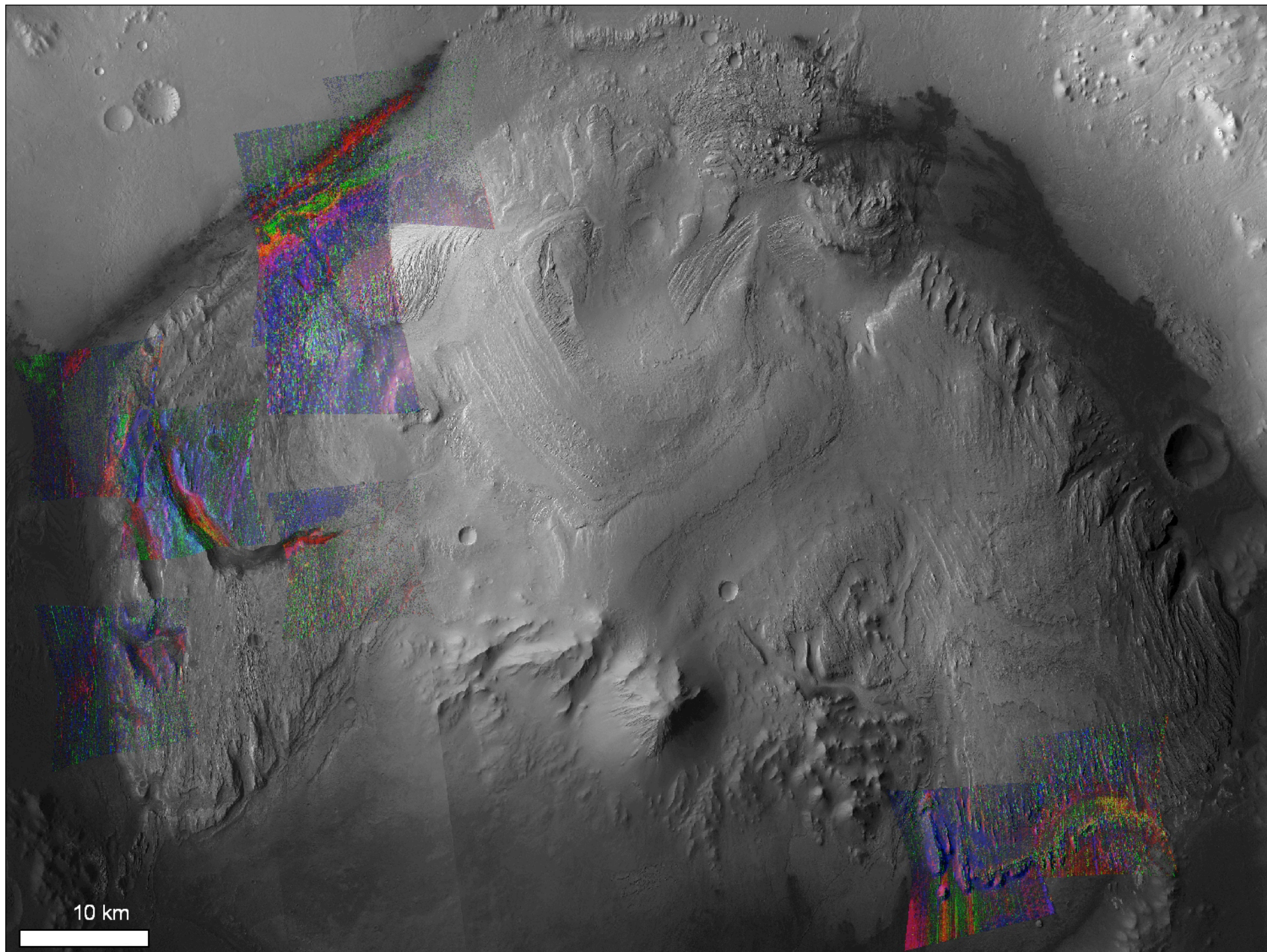


Gale Crater



Gale Crater





CRISM mineral parameter maps on CTX mosaic

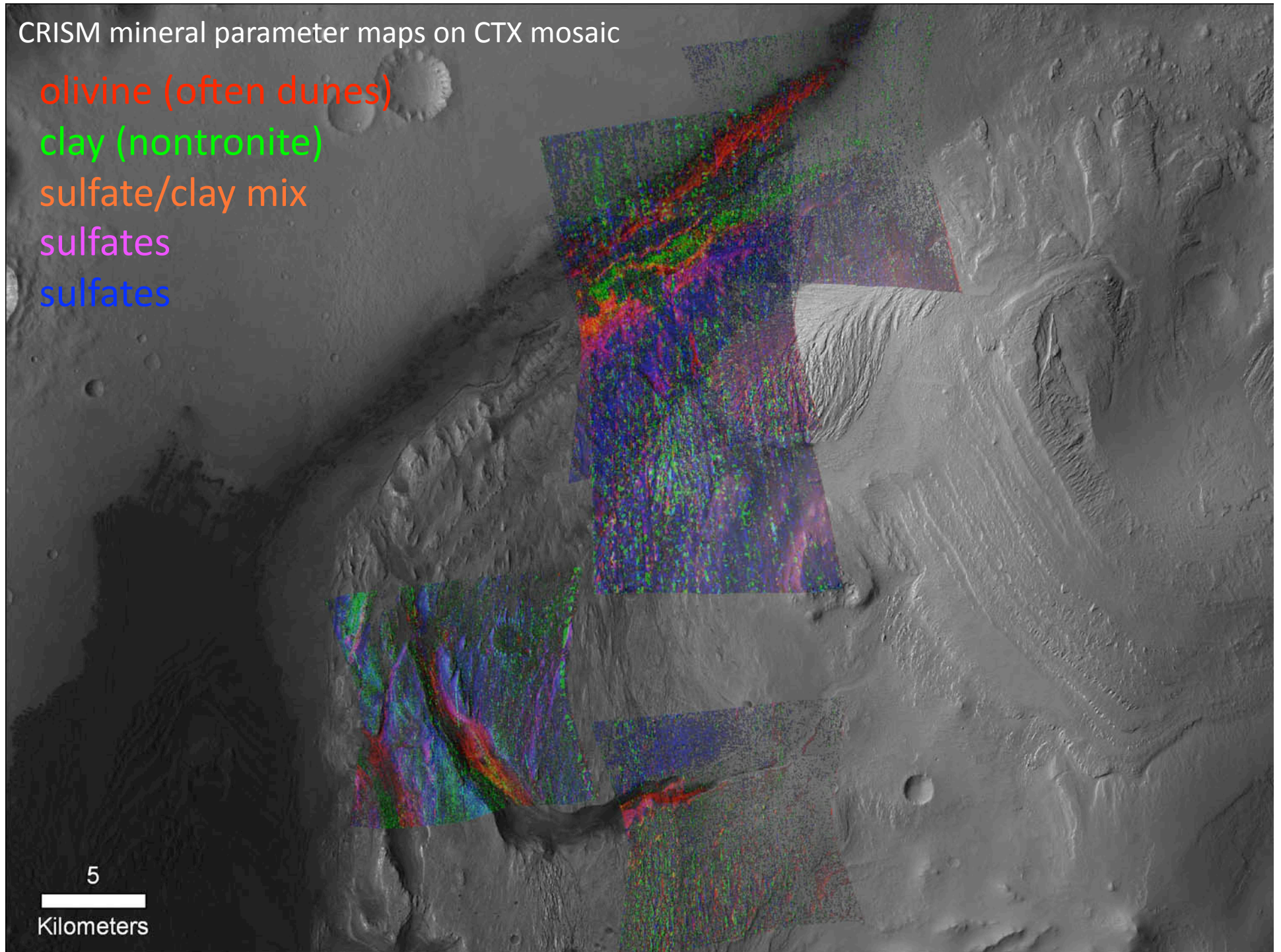
olivine (often dunes)

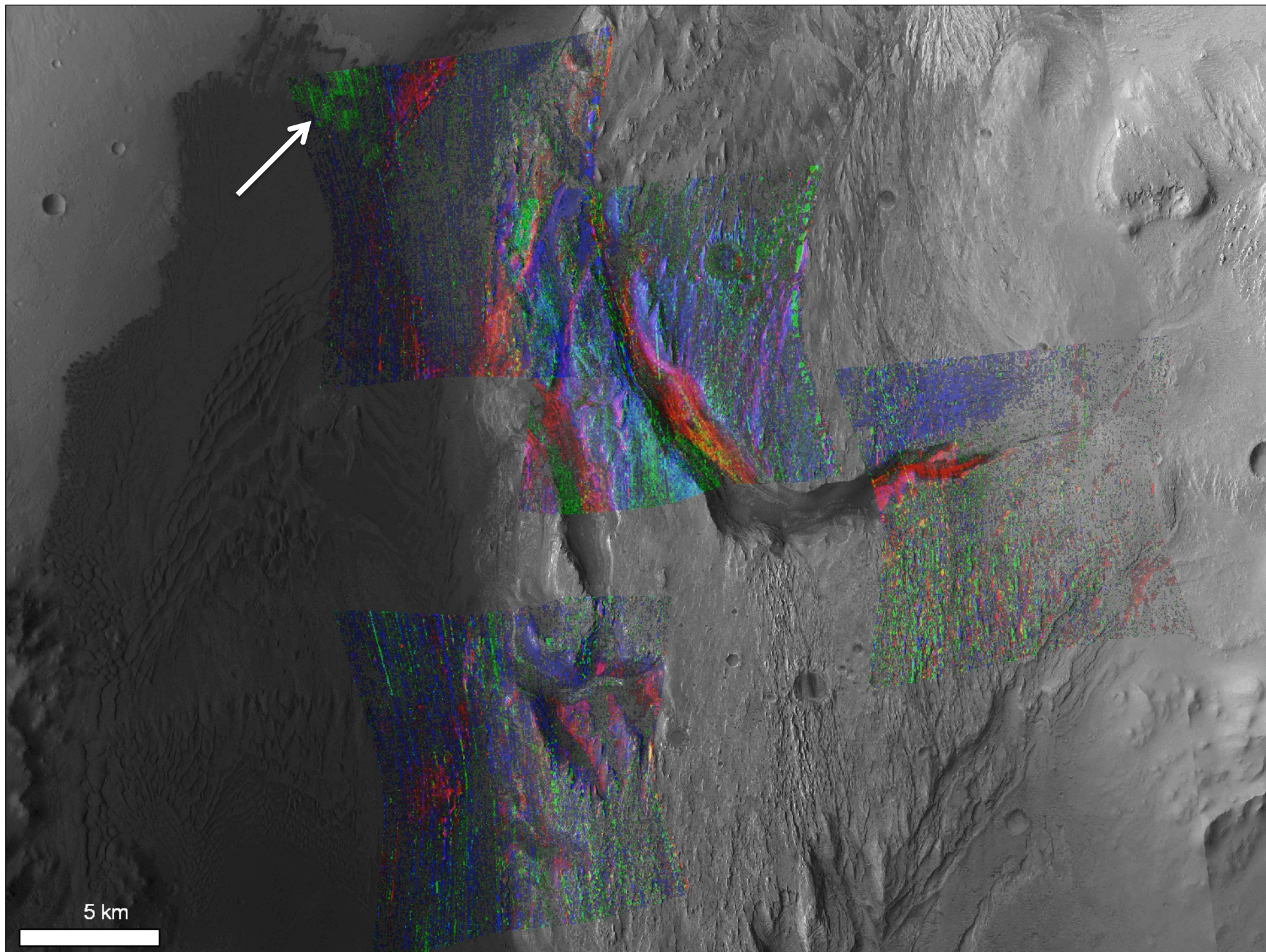
clay (nontronite)

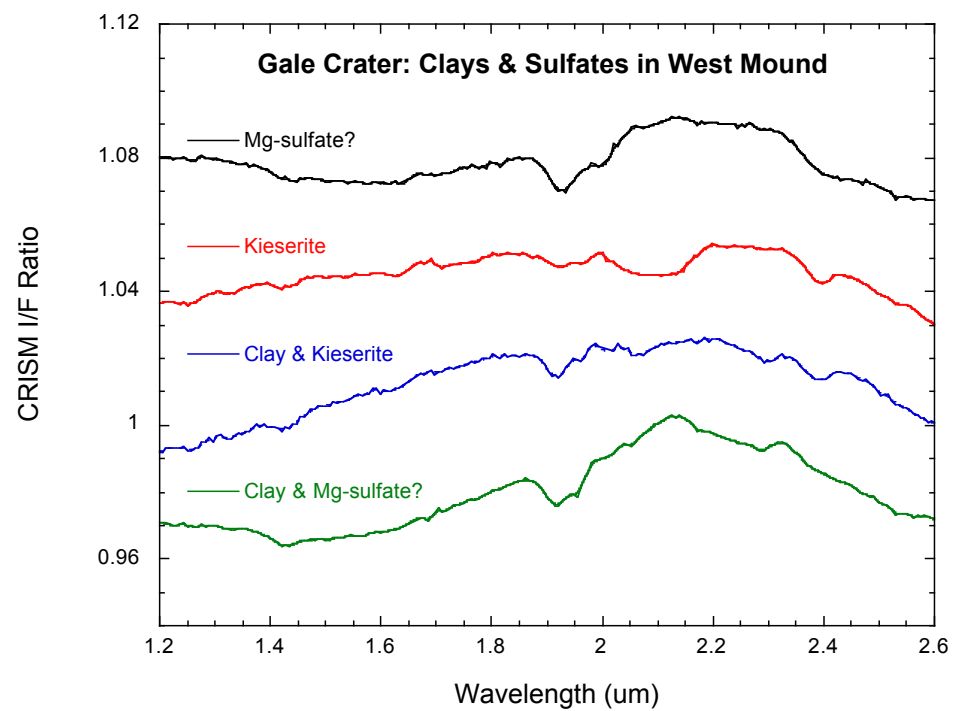
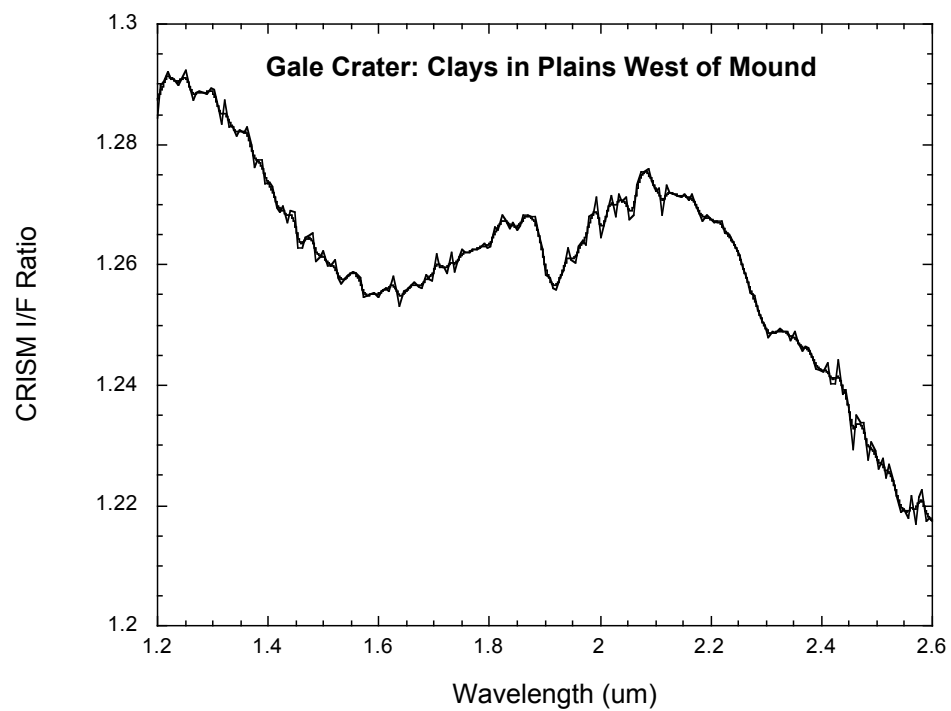
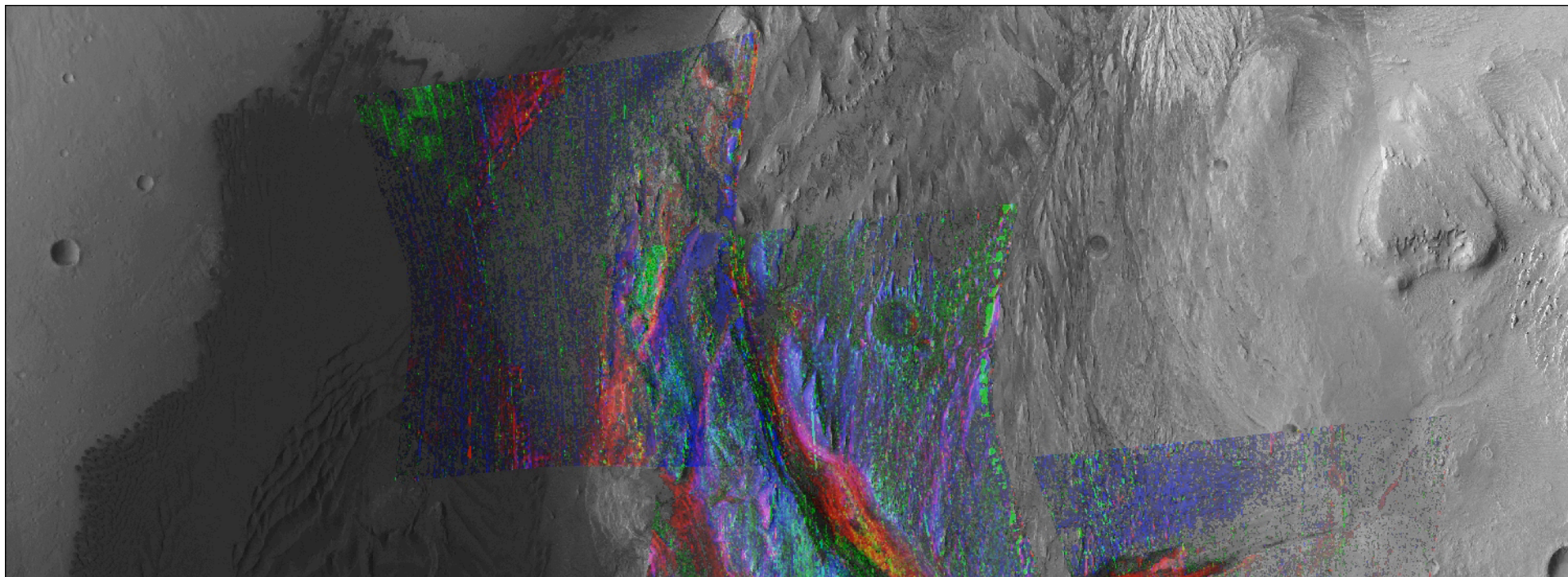
sulfate/clay mix

sulfates

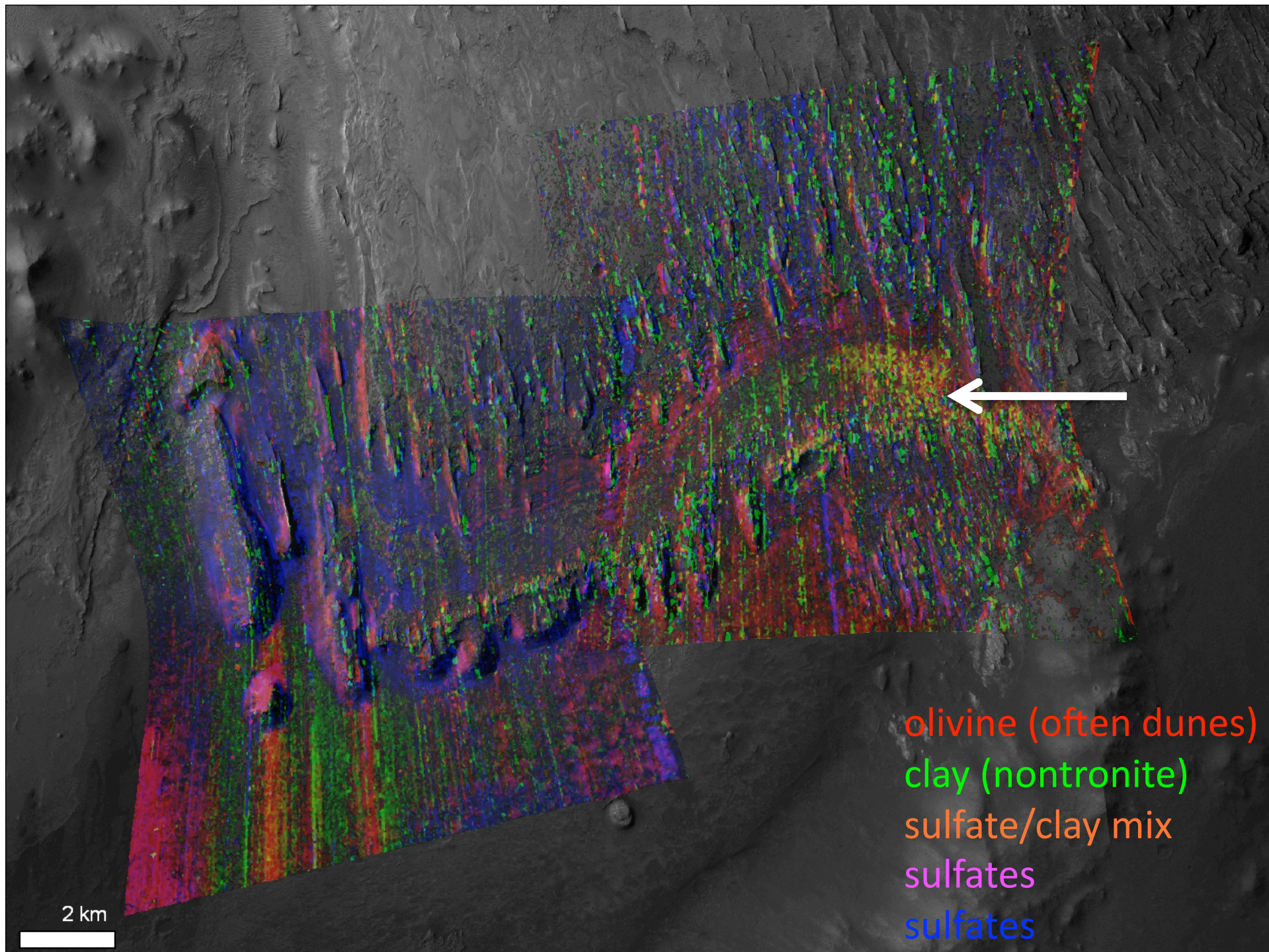
sulfates

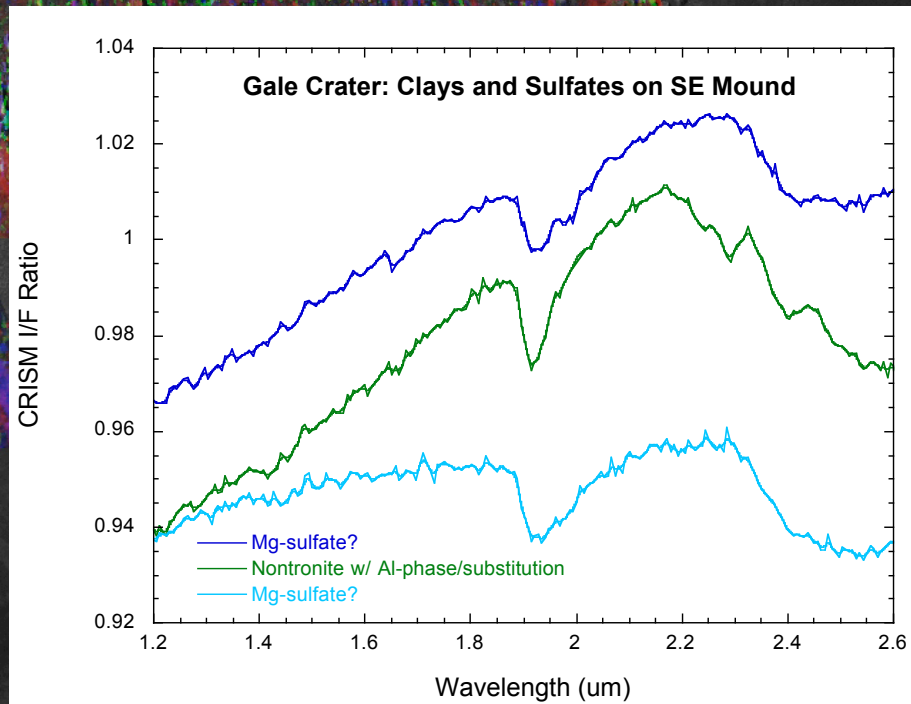
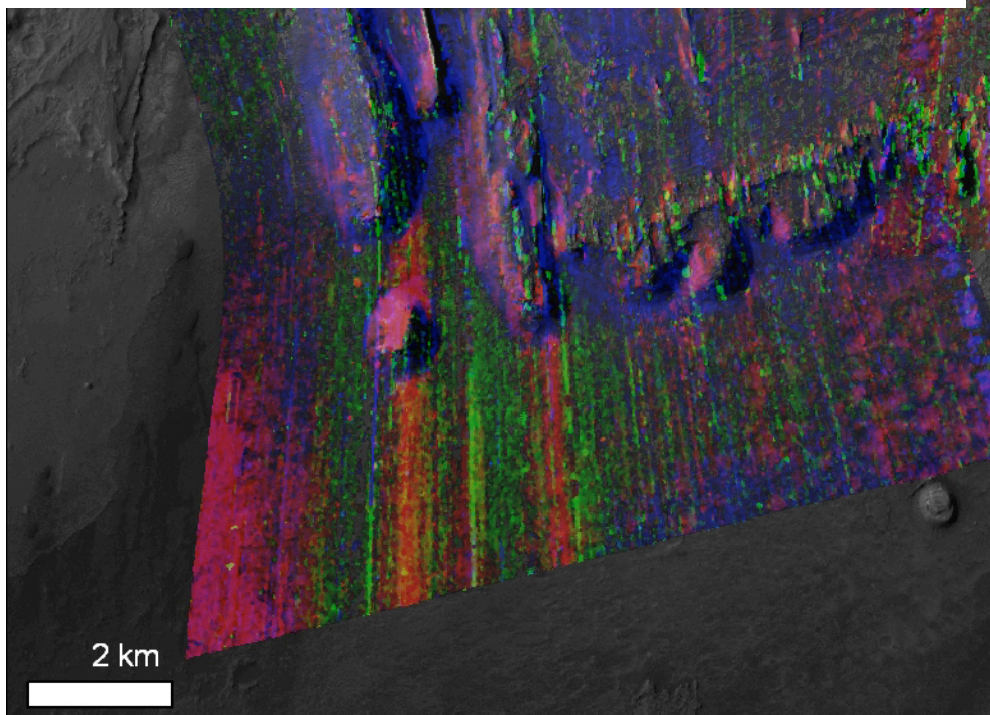
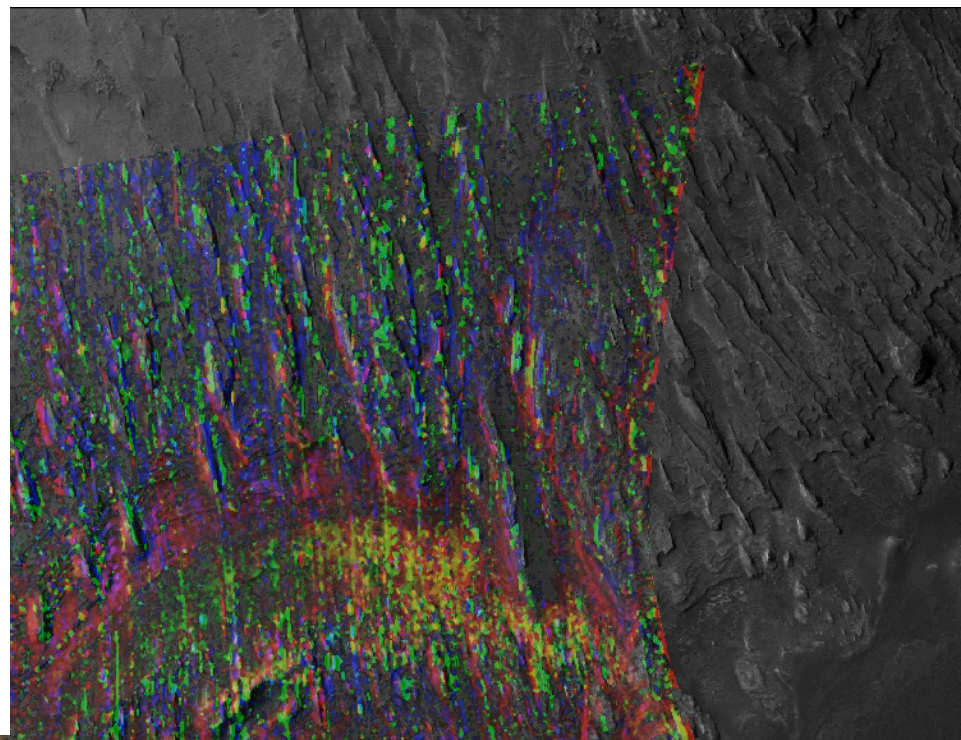
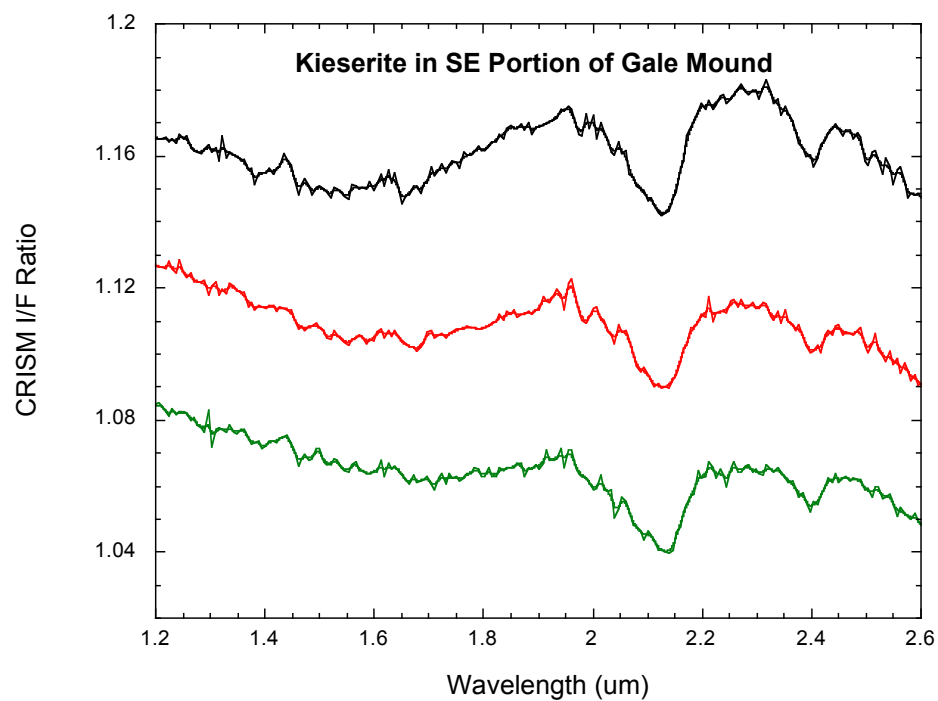






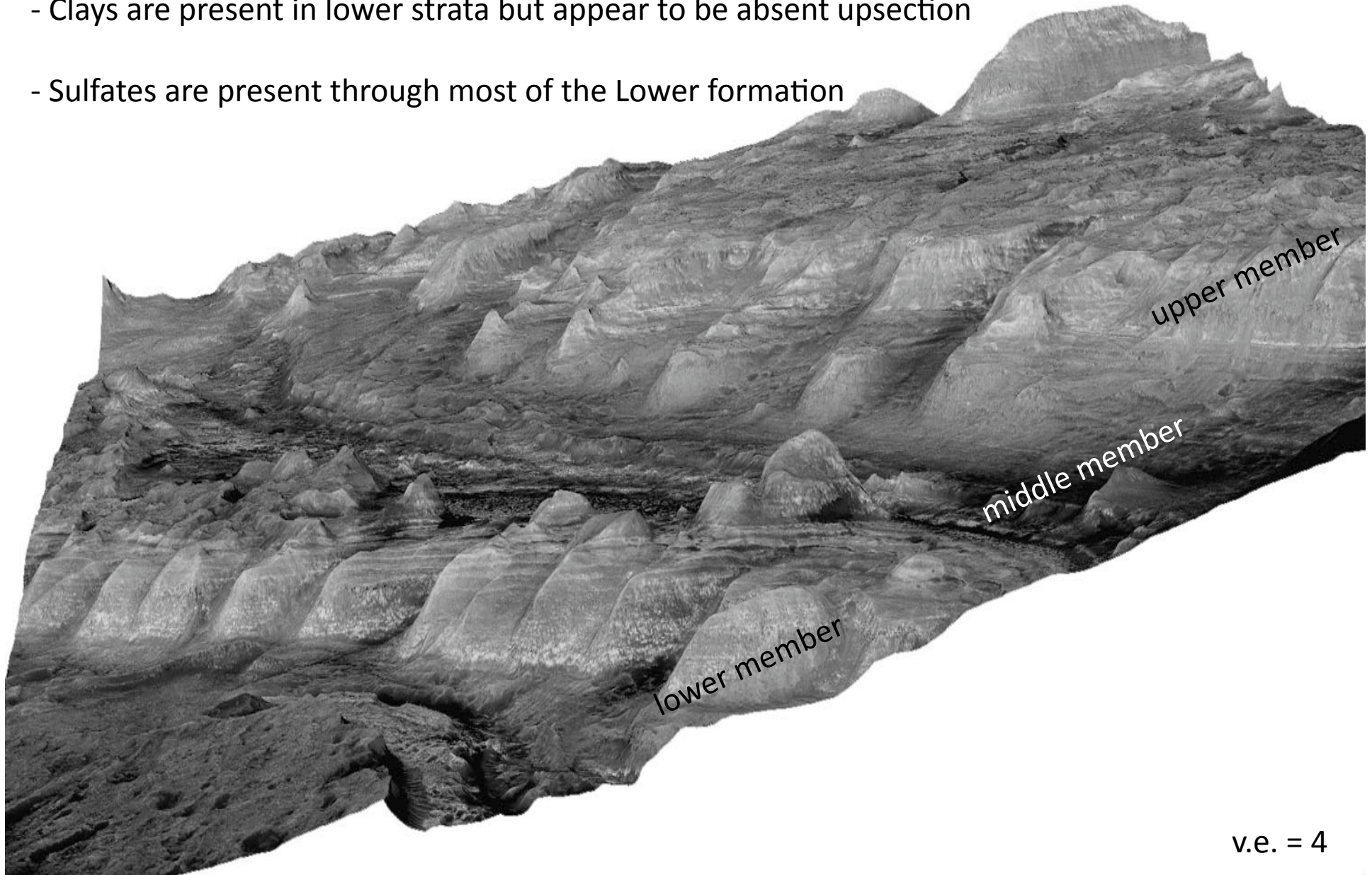






Clay & sulfate-bearing strata in the Lower formation of the Gale mound

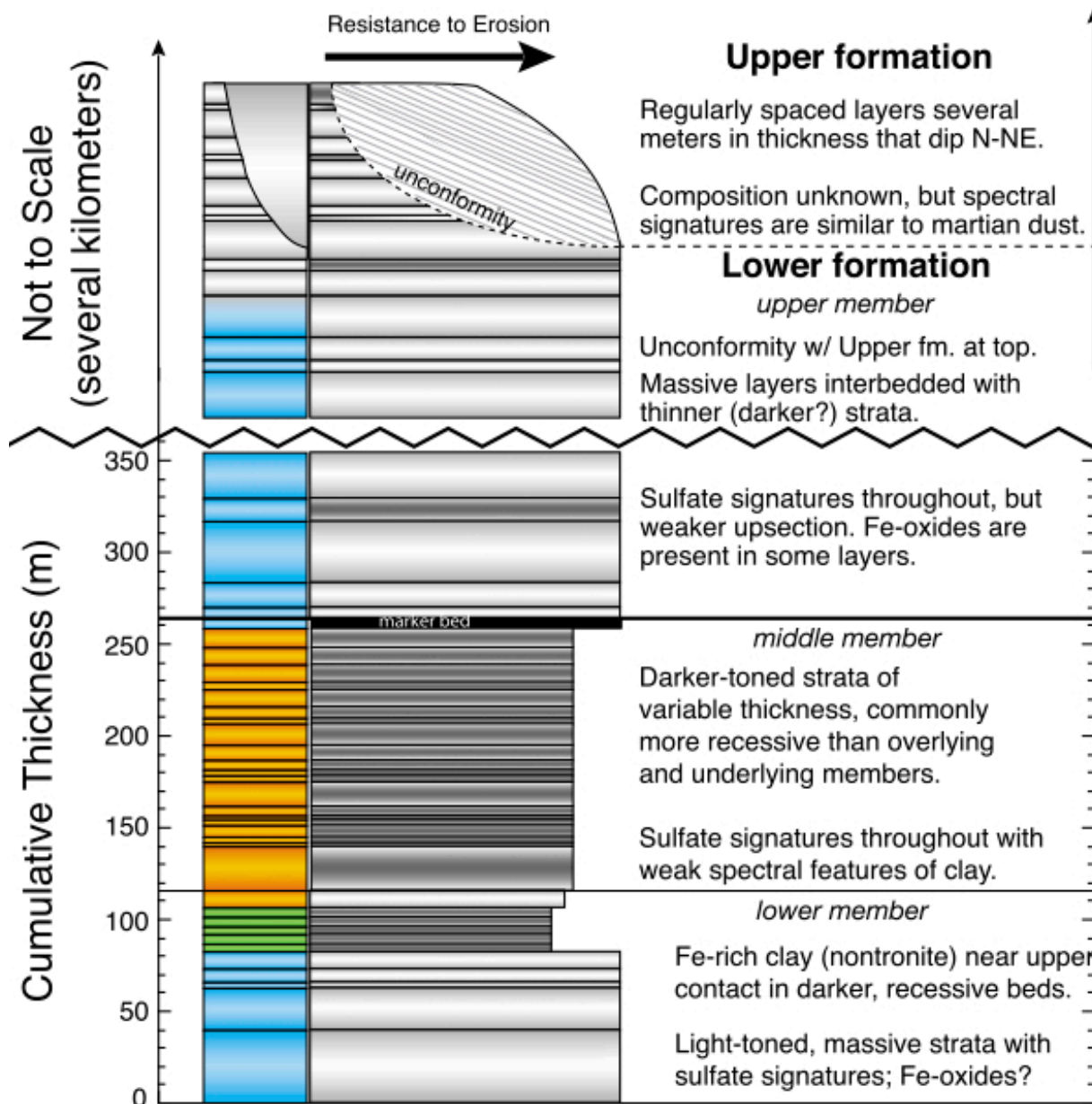
- Clays are present in lower strata but appear to be absent upsection
- Sulfates are present through most of the Lower formation



Mineralogy

Morphology

Interpretations/Comments



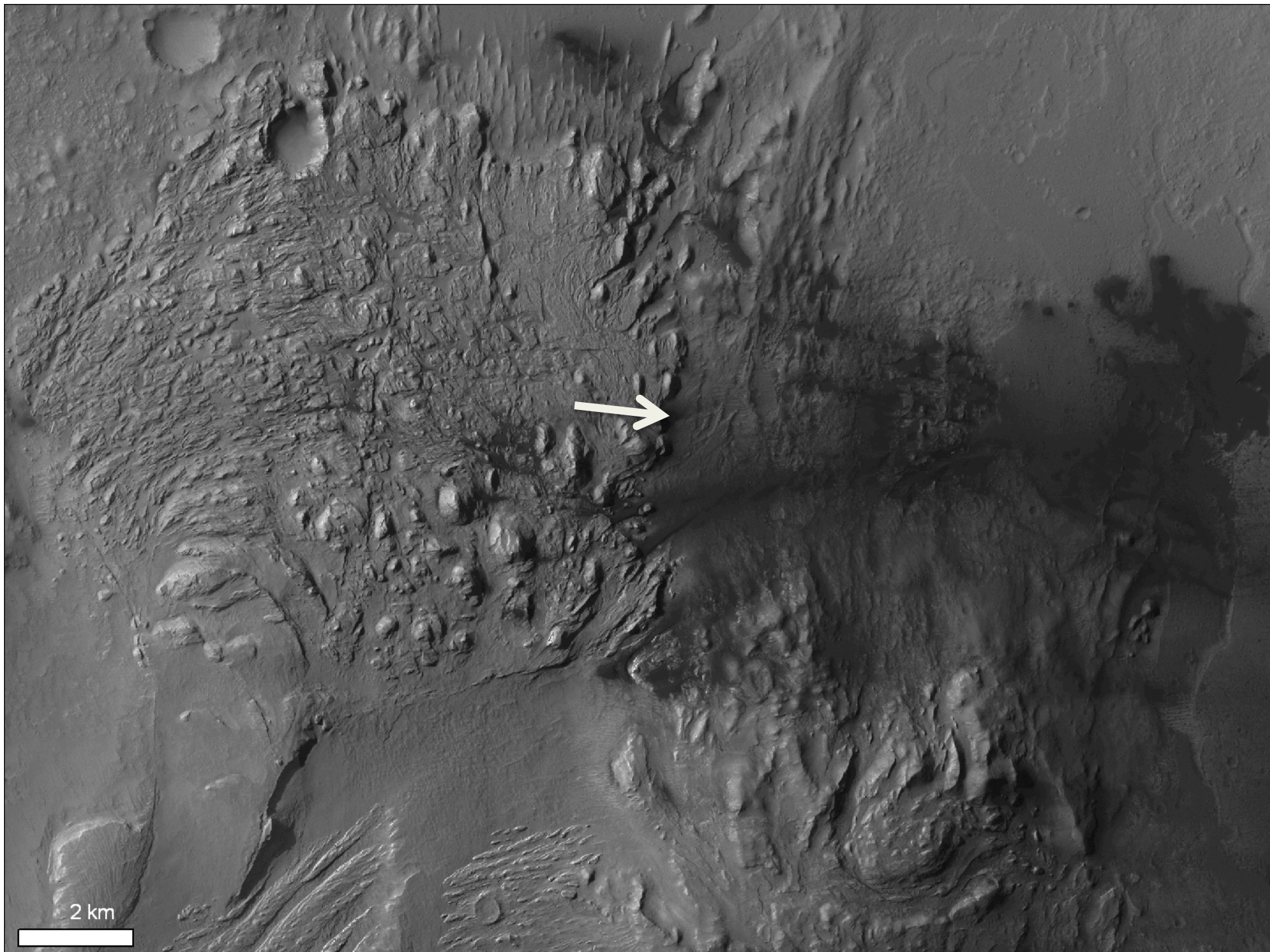
Current data reveal several distinct stratigraphic packages

- Clays are in recessive beds located just below the lower/middle unit contact.

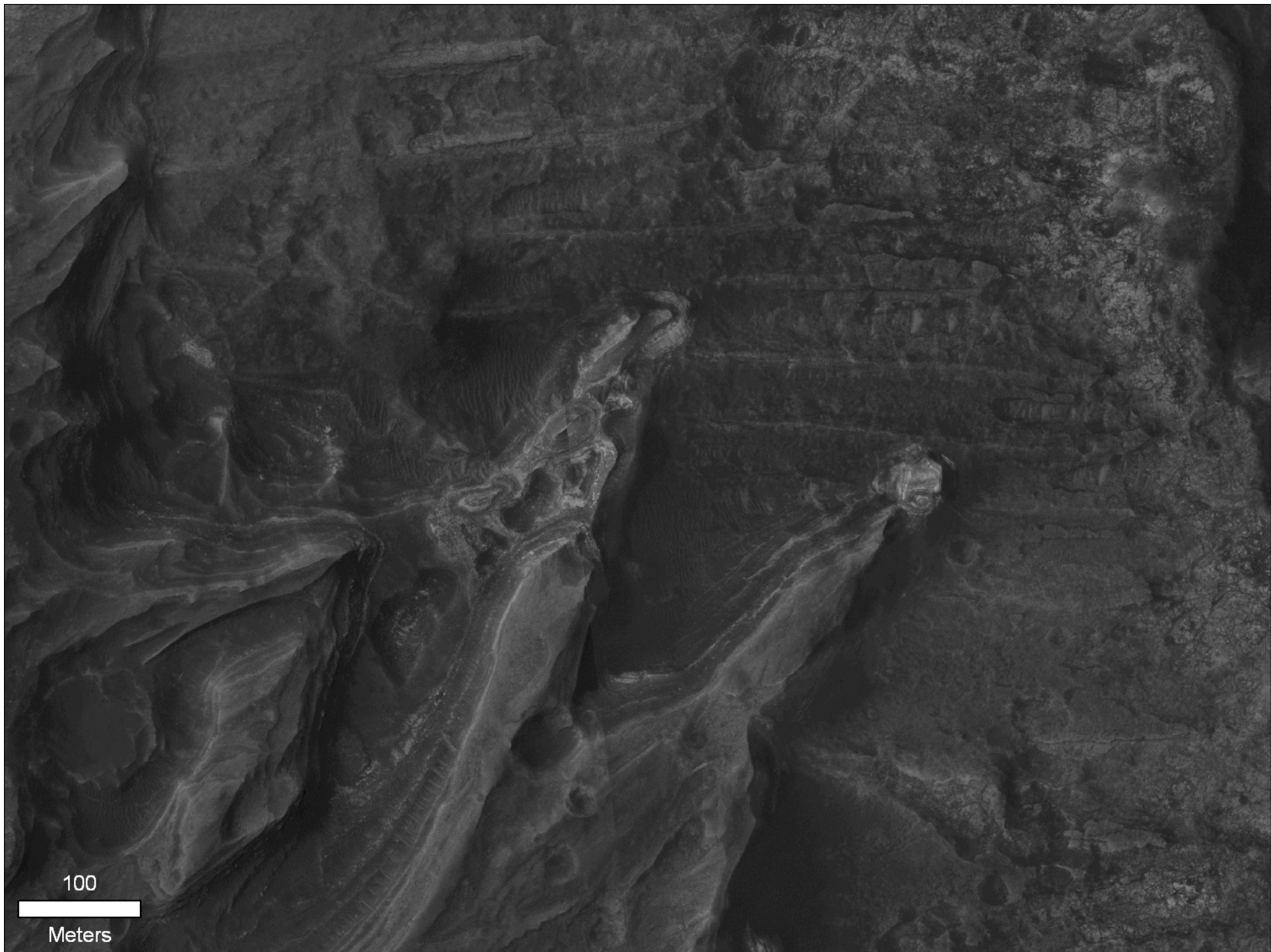
- Some evidence for repeat of units, but need more data to verify.

- Morphology, mineralogy, topography, cross-sections approach the question of stratigraphy independently...

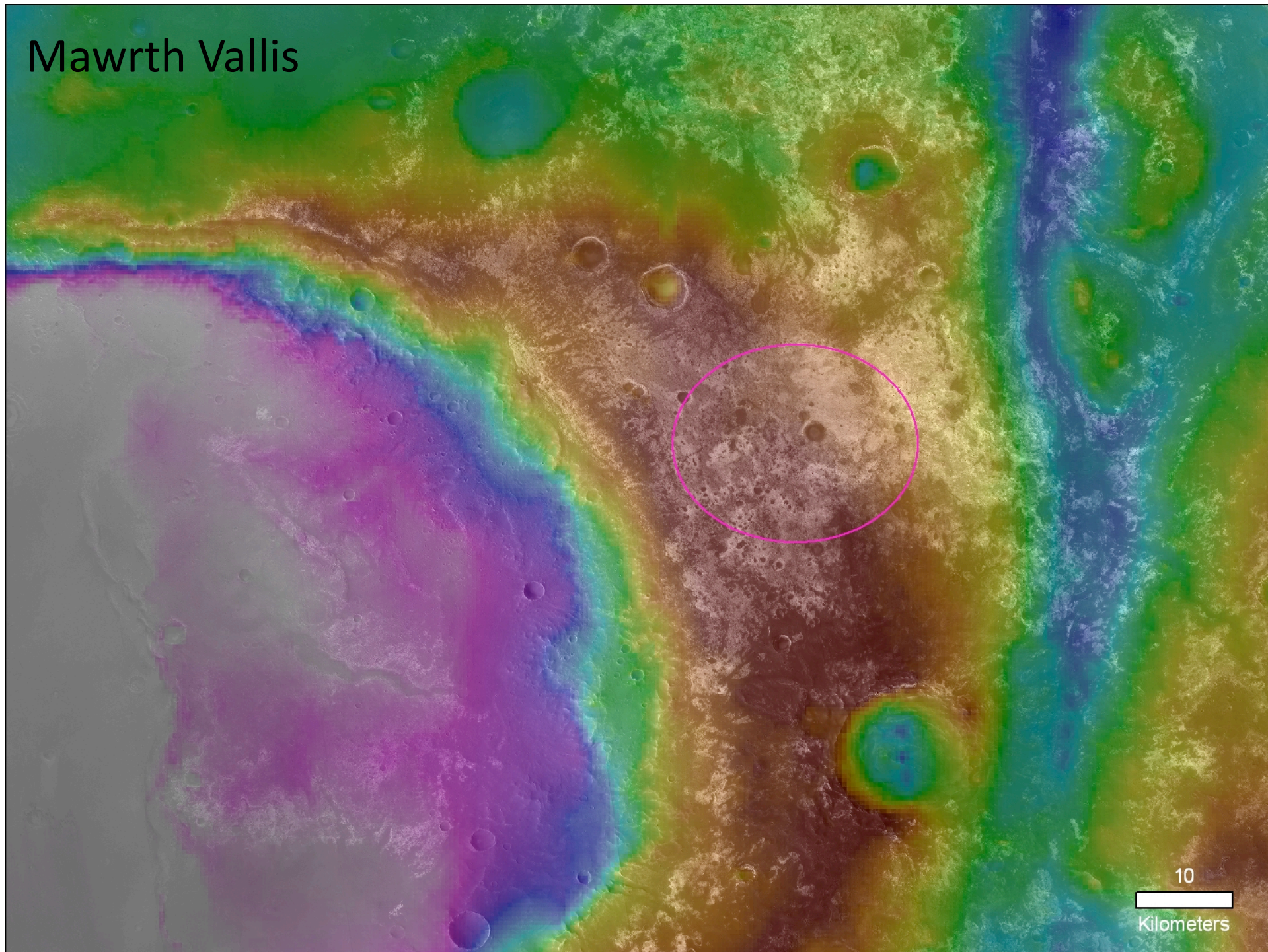
..but yield a consistent story.

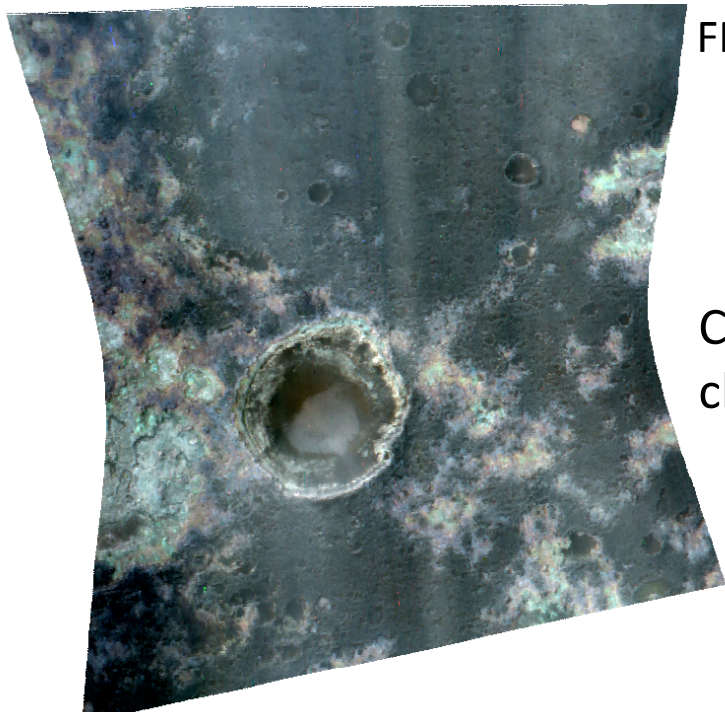






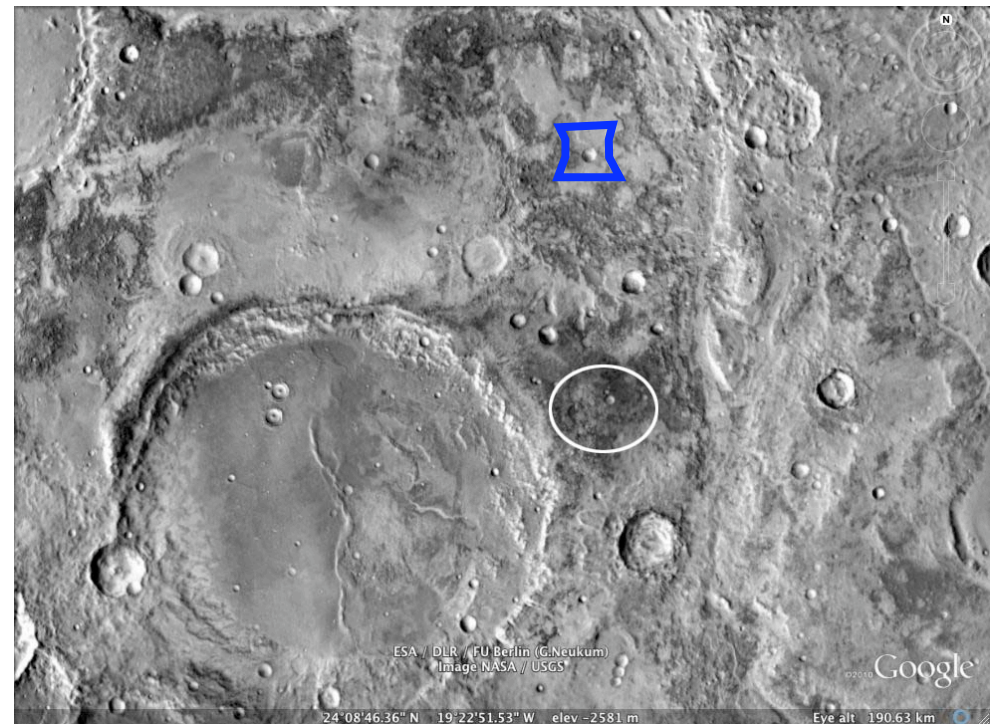
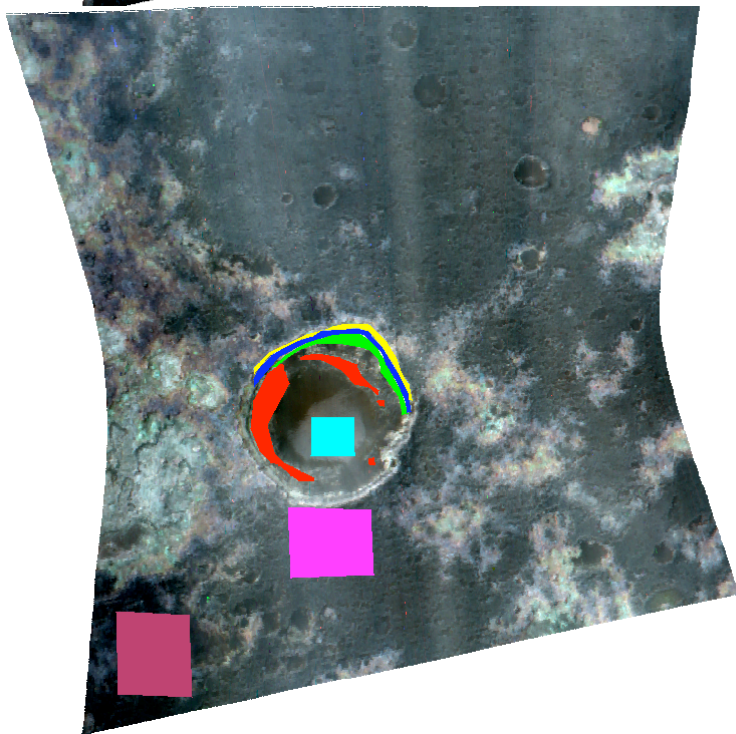
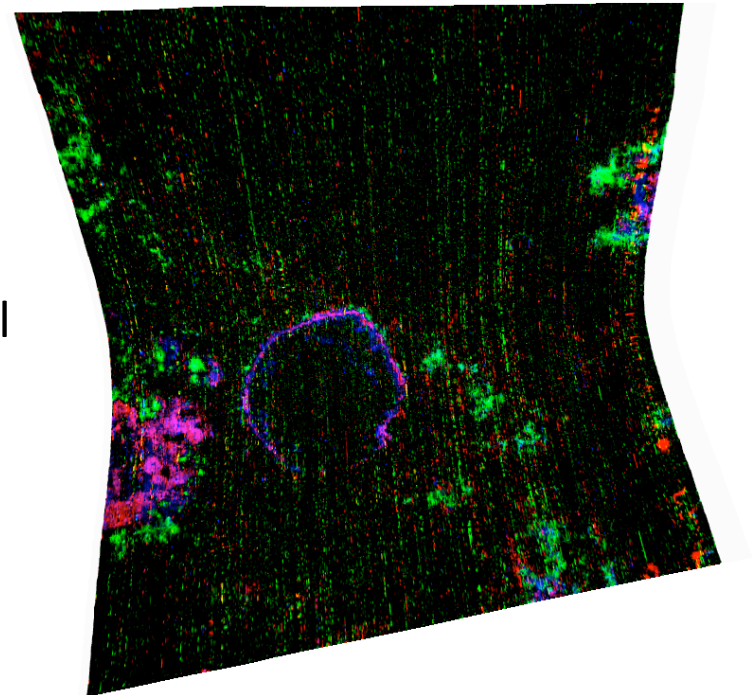
Mawrth Vallis

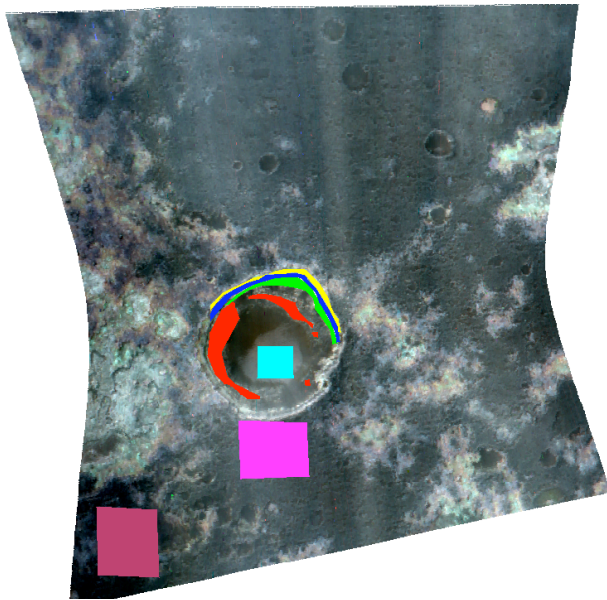




FRT0000C596

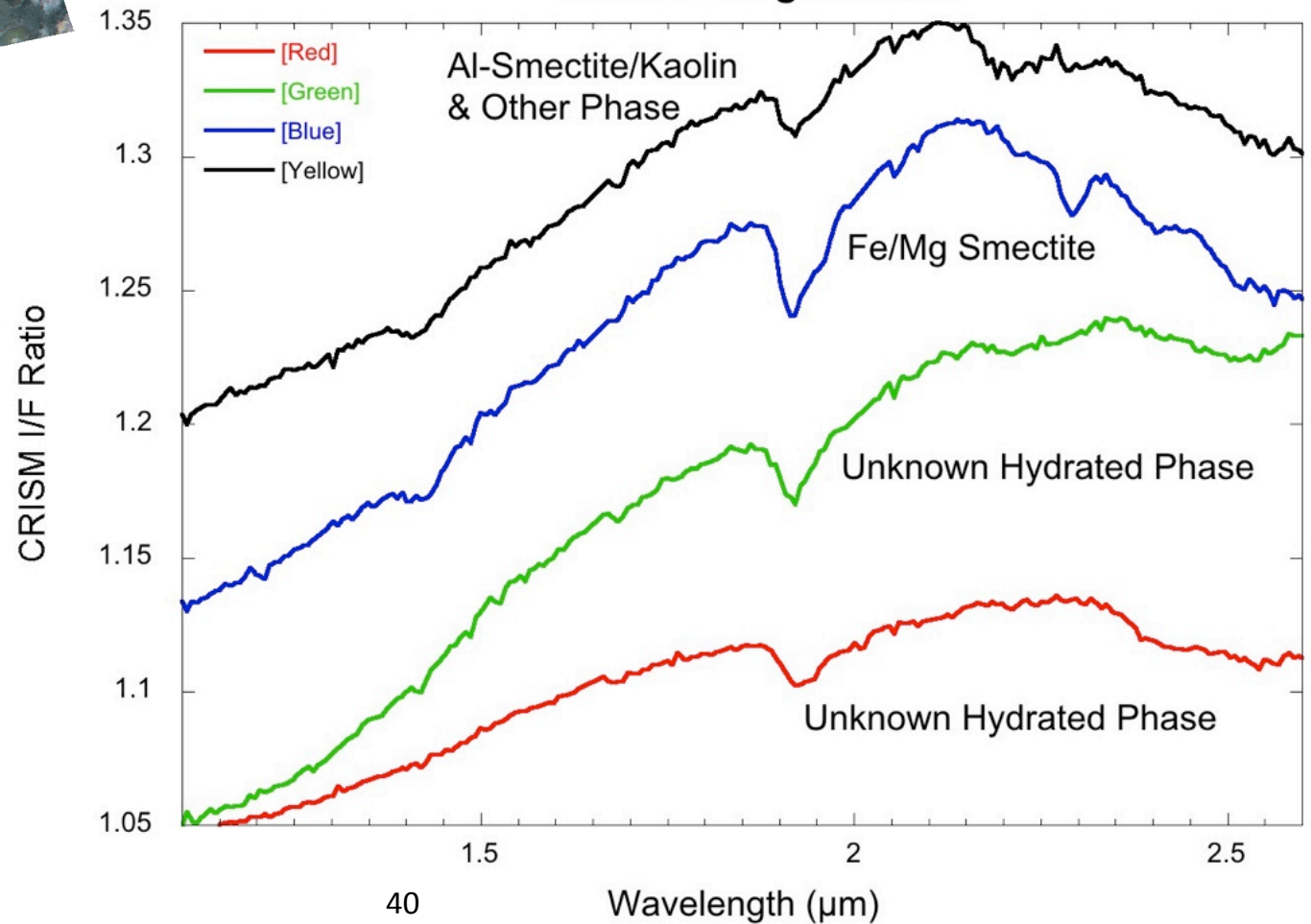
Craters show mineral changes with depth.





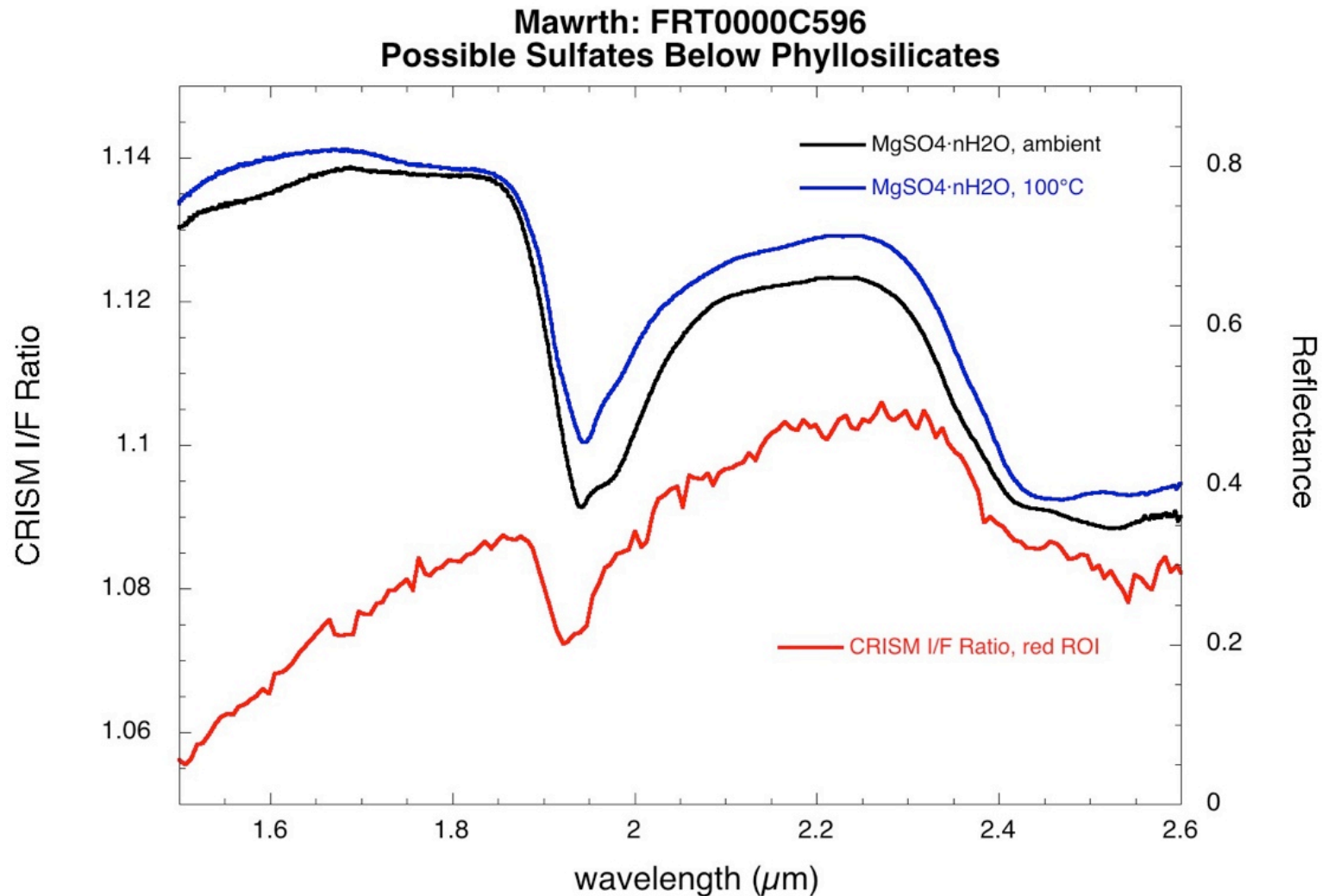
There is a distinct hydrated phase underneath the phyllosilicates.

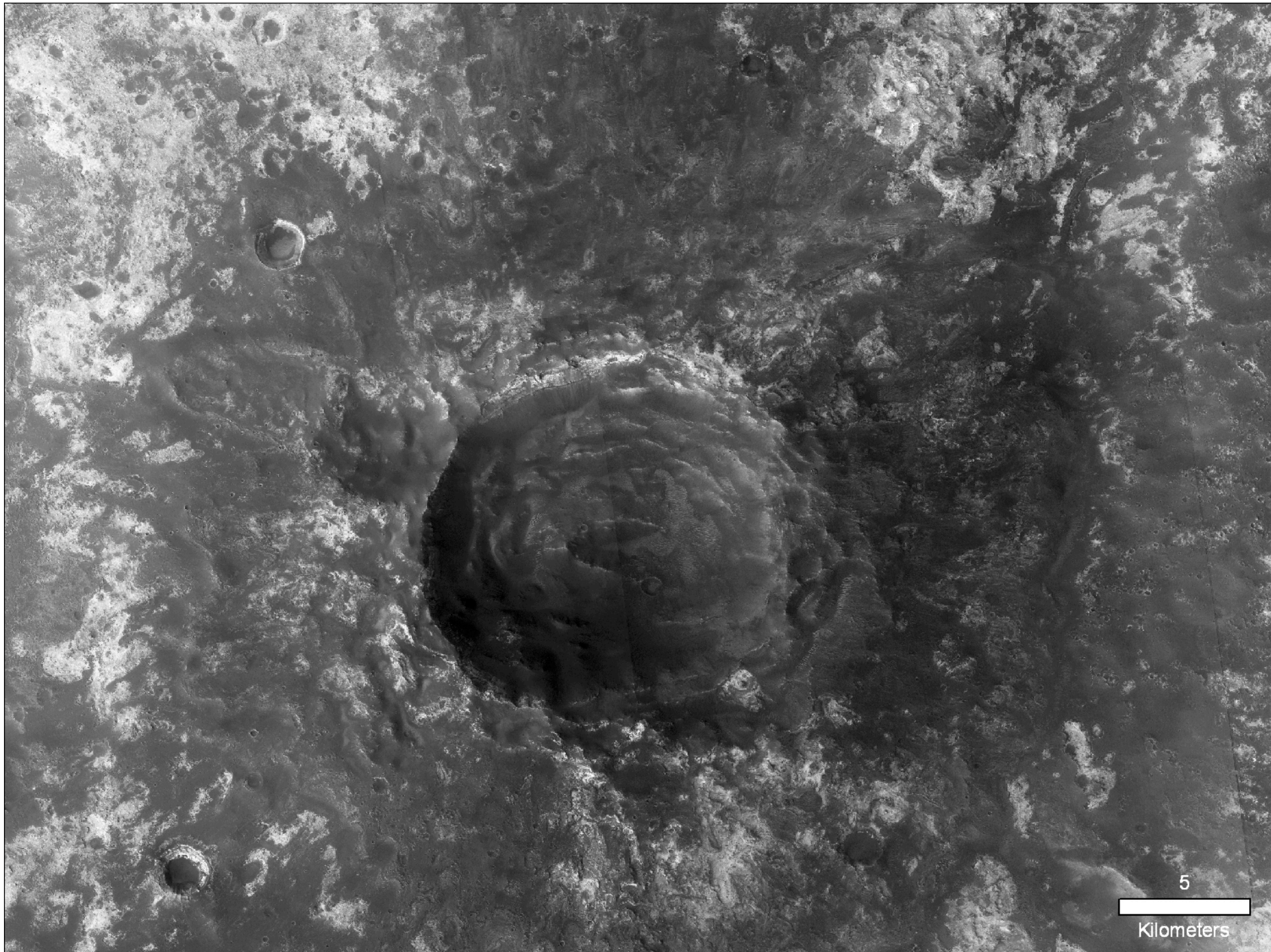
Mawrth: FRT0000C596
Ratio to Magenta ROI

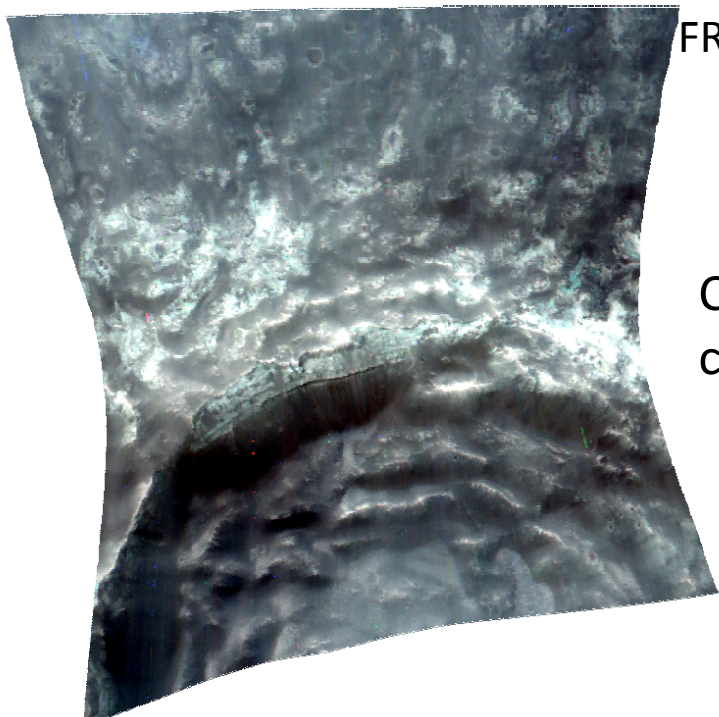


Wray et al. (2010) discuss presence of bassanite,
is this additional evidence for sulfates below clays?

The hydrated phase(s) could be Mg-sulfate, but the 1.9 μm band is a
bit shortward of where it should be...zeolites? other?

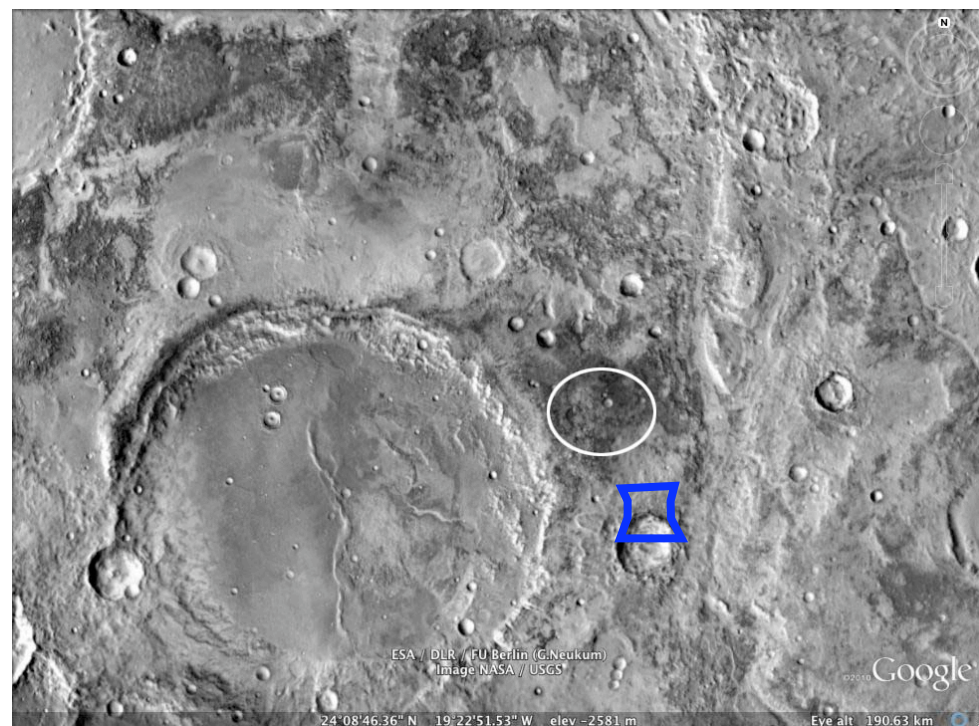
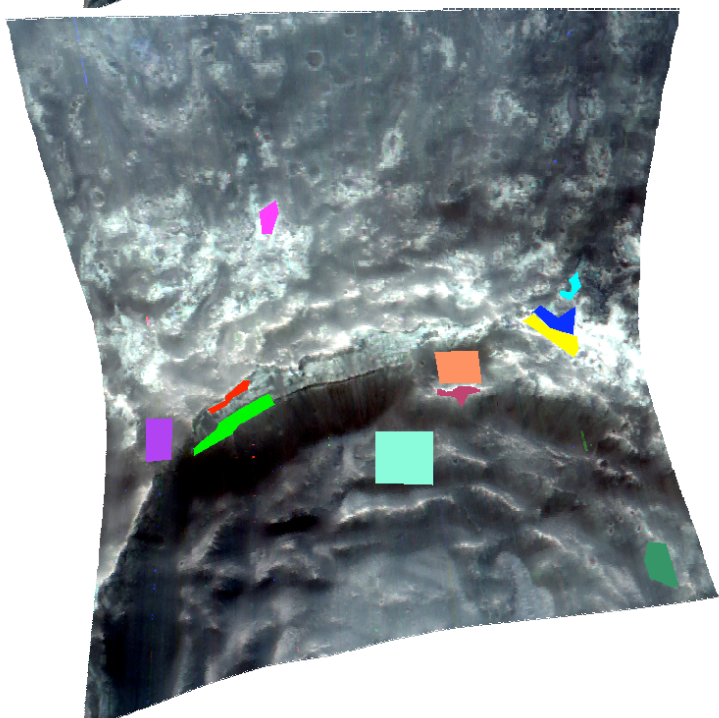
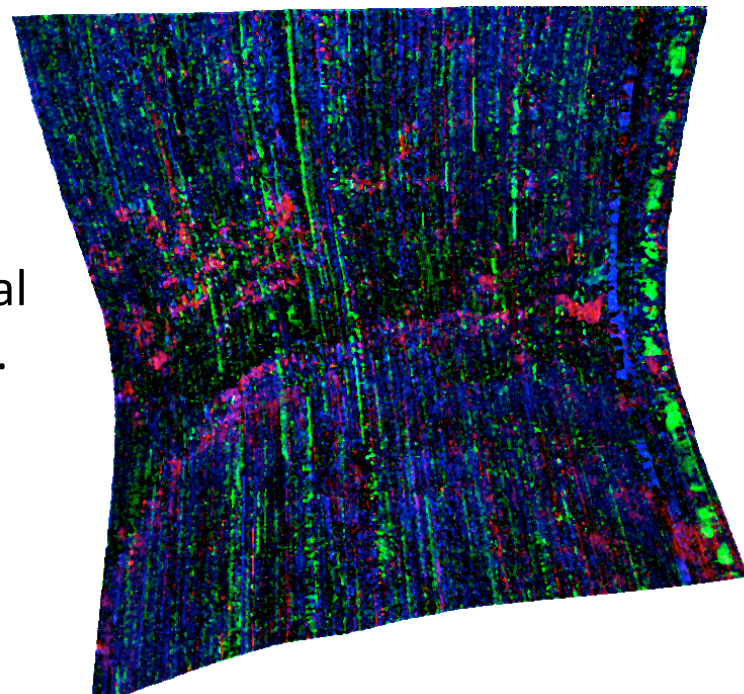


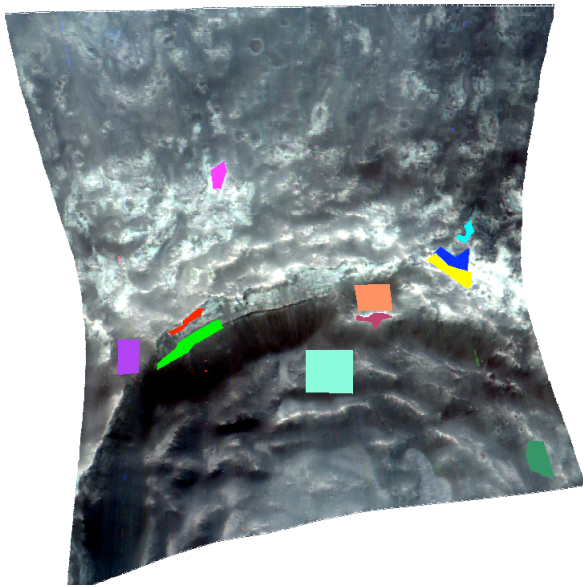




FRT00016E2D

Craters show mineral changes with depth.





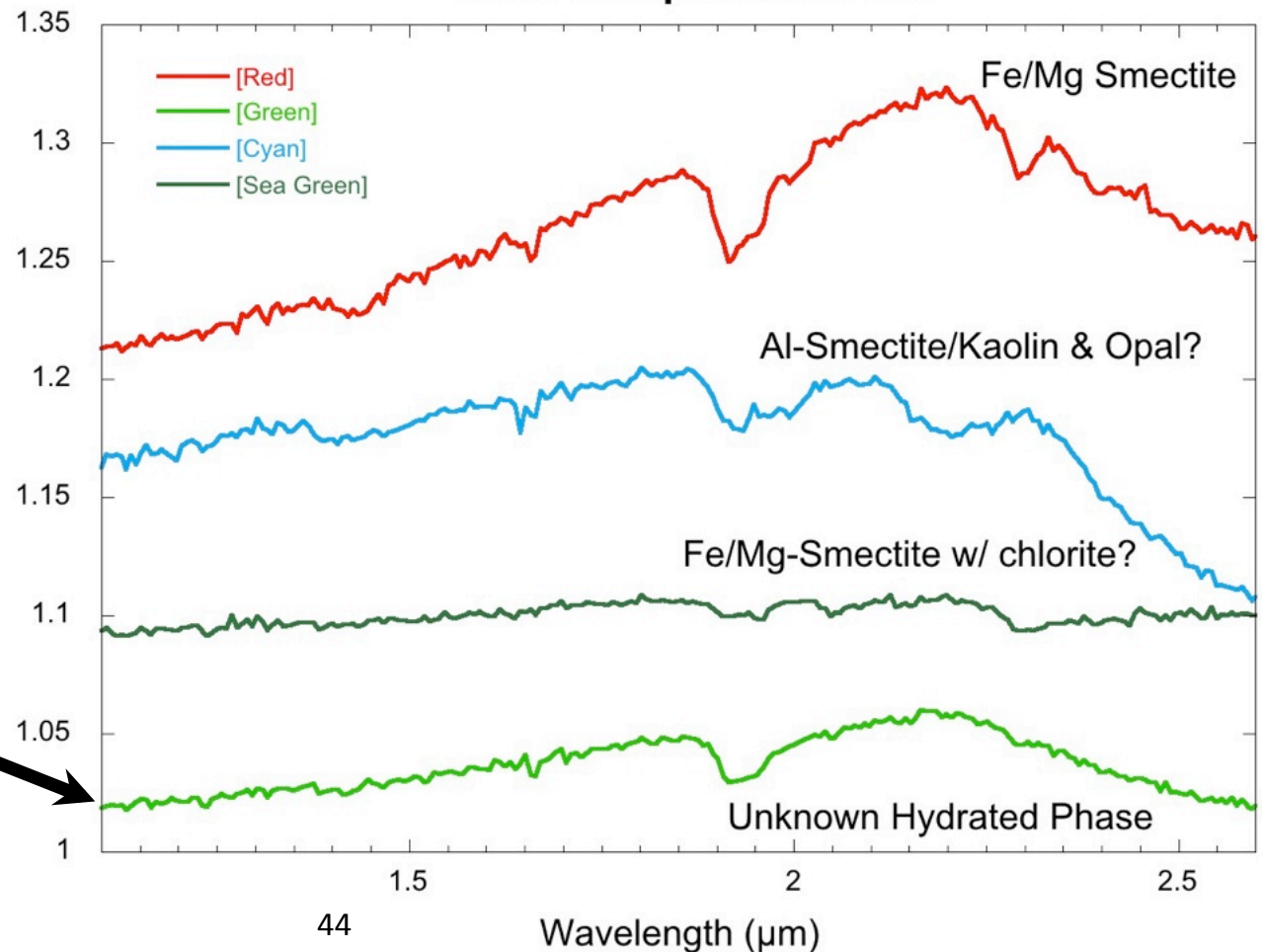
Al-bearing phases are on top of the Fe/Mg smectites.

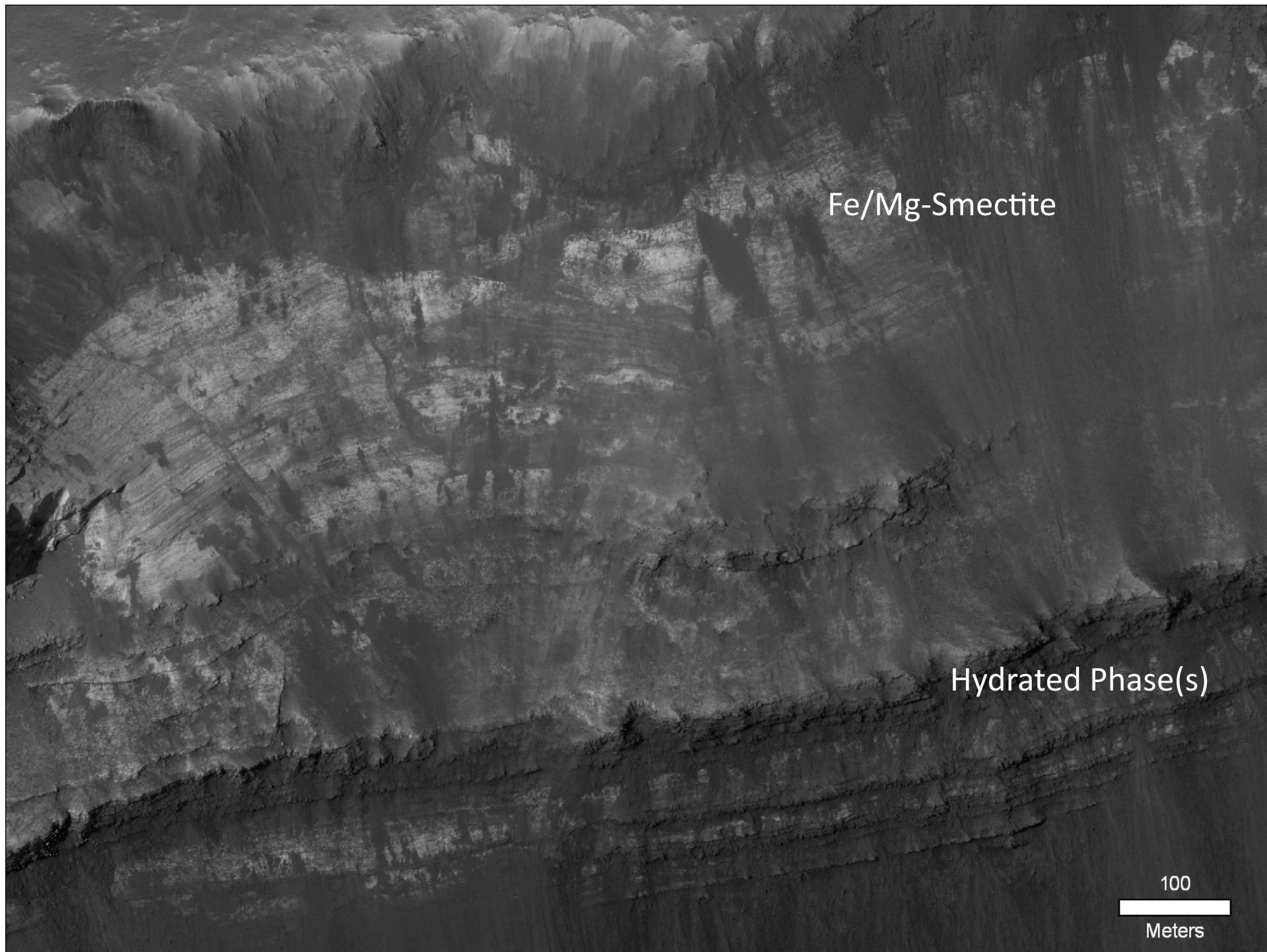
There is a hydrated phase beneath the Fe/Mg smectites.

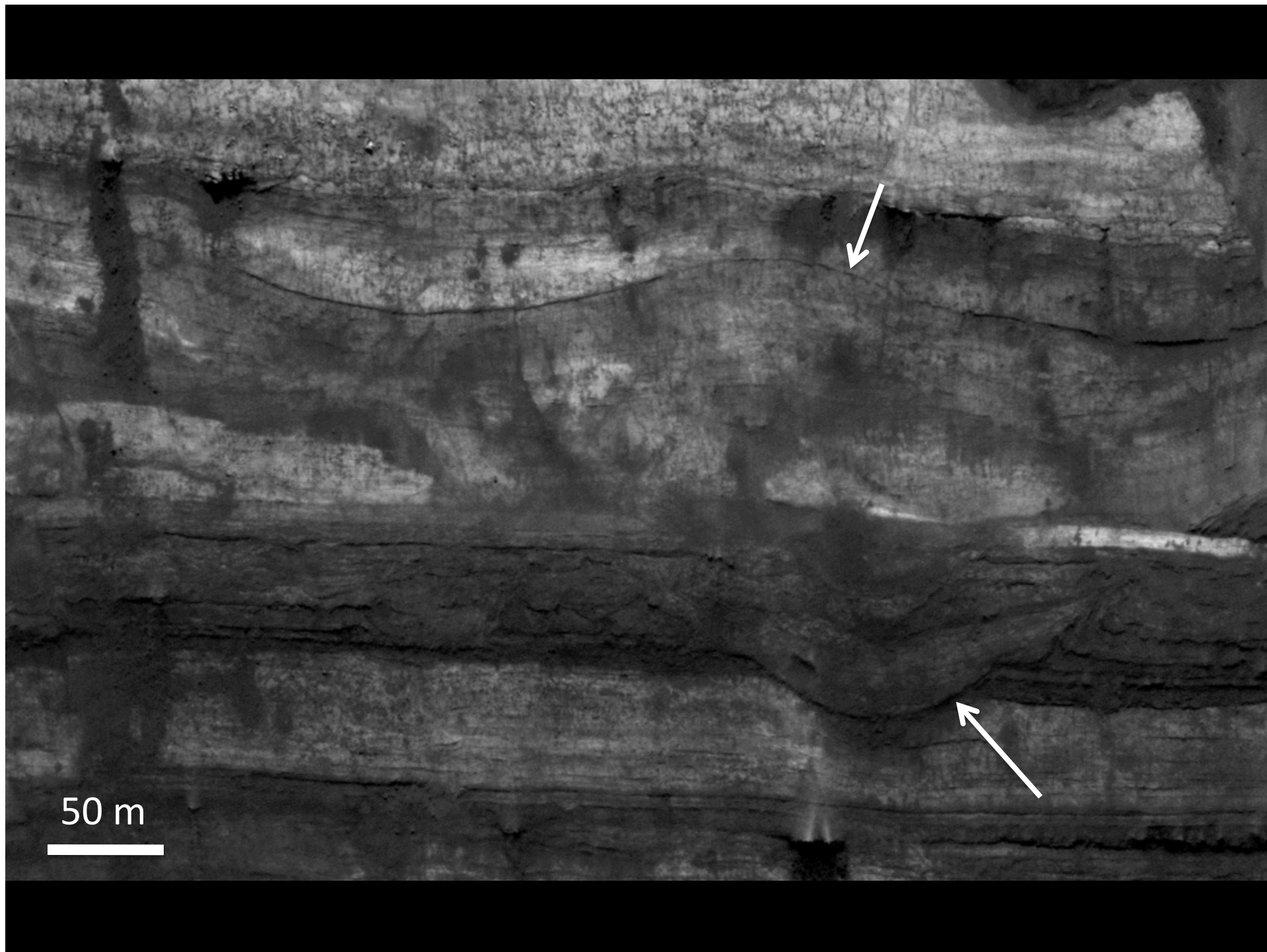
The spectrum is too ambiguous for a proper mineral ID, but features are consistent with a hydrated sulfate or other salt.

CRISM I/F Ratio

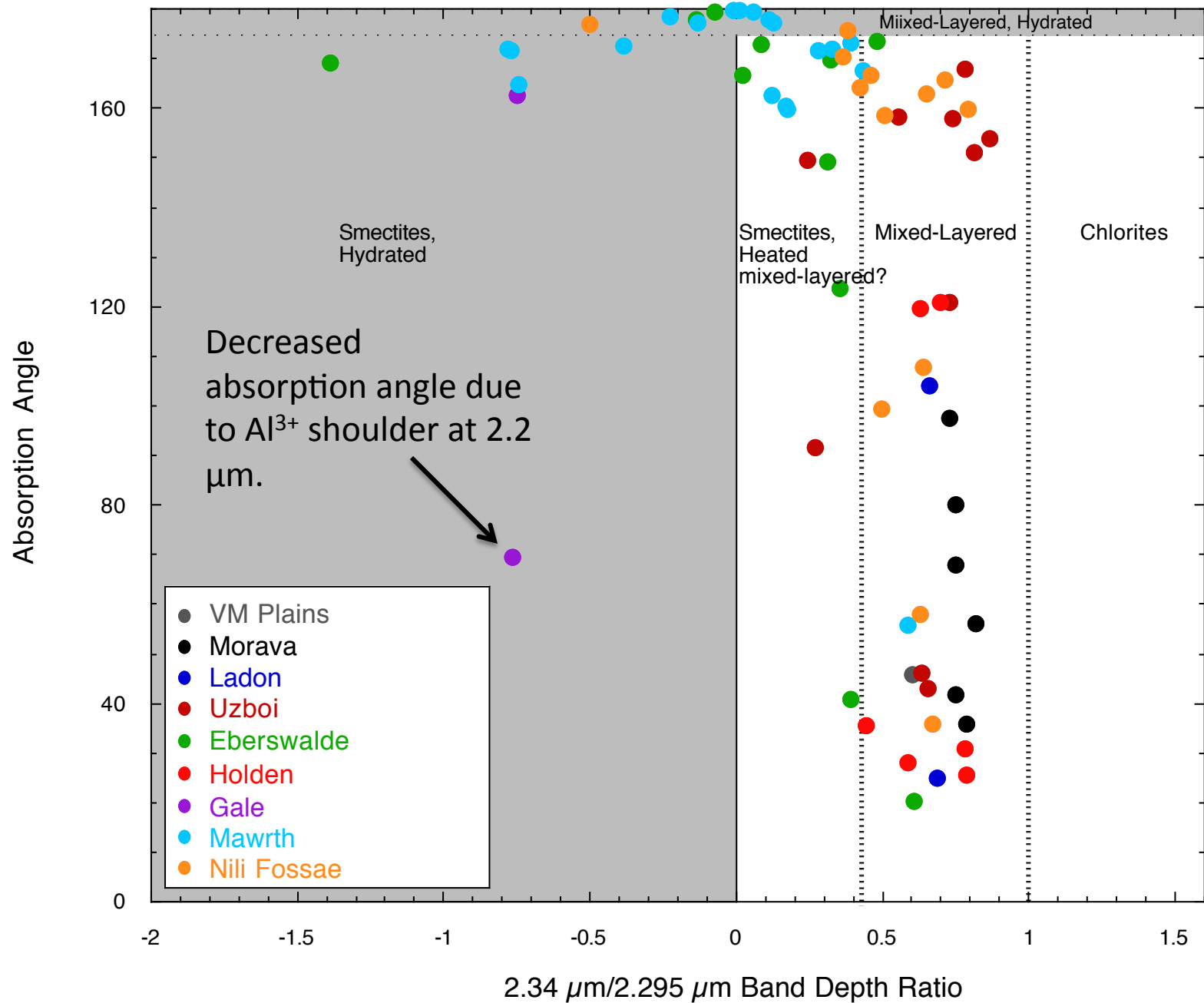
Mawrth: FRT00016E2D
Ratio to Aquamarine ROI







Clays in Ancient Crust



What About Full Alteration Assemblages?

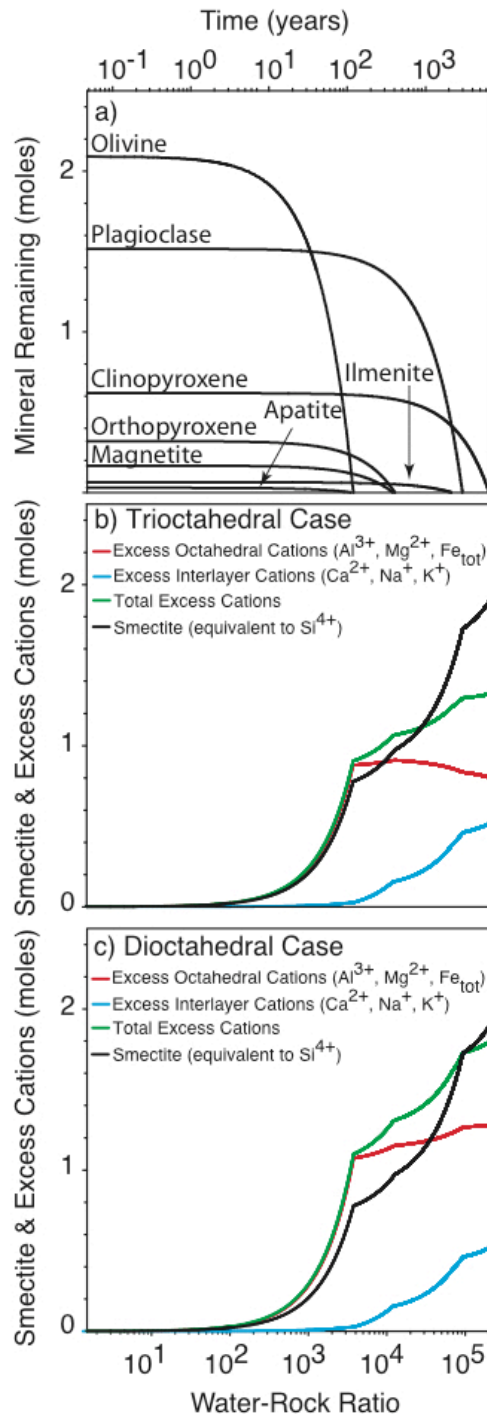
Formation of smectites via chemical weathering of basalt requires significant amounts of Si.

Smectite formation results in an excess of cations presumed to reside in complementary 'salts' with anions such as:

CO_3^{2-} , SO_3^{2-} , SO_4^{2-} , Cl^- , OH^- , etc.

Yet such minerals are largely missing (or not detected) in the Noachian rock record.

Determining the composition and/or fate of these 'missing salts' is key to understanding climate feedback processes on early Mars.



(Figure from Milliken et al., 2009)

Gale Crater: Clays & Sulfates

- Fe-rich smectite (nontronite) w/ Al^{3+}
- Mg-sulfates (mono and polyhydrated)
- mafic signatures in rocks & aeolian material
- lower ~1 km dominated by sulfates
- crystalline hematite....from sulfate strata?
- origin of clay/sulfate unknown
- fluvial system being exhumed
- strata in Upper formation apparently lack evidence of hydrous minerals

Mawth Vallis: Clays & Sulfates(?)

- Al-rich clay minerals
- Fe-rich smectite (nontronite)
- Hydrous phases....sulfates?
- Al-clays mixed with sulfates?
- origin of clay/sulfate unknown
- most strata planar & exhibit parallel bedding
- In crater S of ellipse, great examples of non-planar bedding, faults/folds, vertical accretion, brecciation, etc.

Holden Crater: Clay Minerals

- Mg/Fe mixed-layer chlorite/smectite, similar to what is seen throughout ULM
- possible non-mixed-layer Mg/Fe-smectite in Uzboi, but not yet observed in Holden
- olivine & pyroxene signatures in crater wall
- clays accessible to MSL are largely consistent with a detrital origin
- association of clays & mafics in crater wall suggest some of those clays may be authigenic

Eberswalde Crater: Clay Minerals

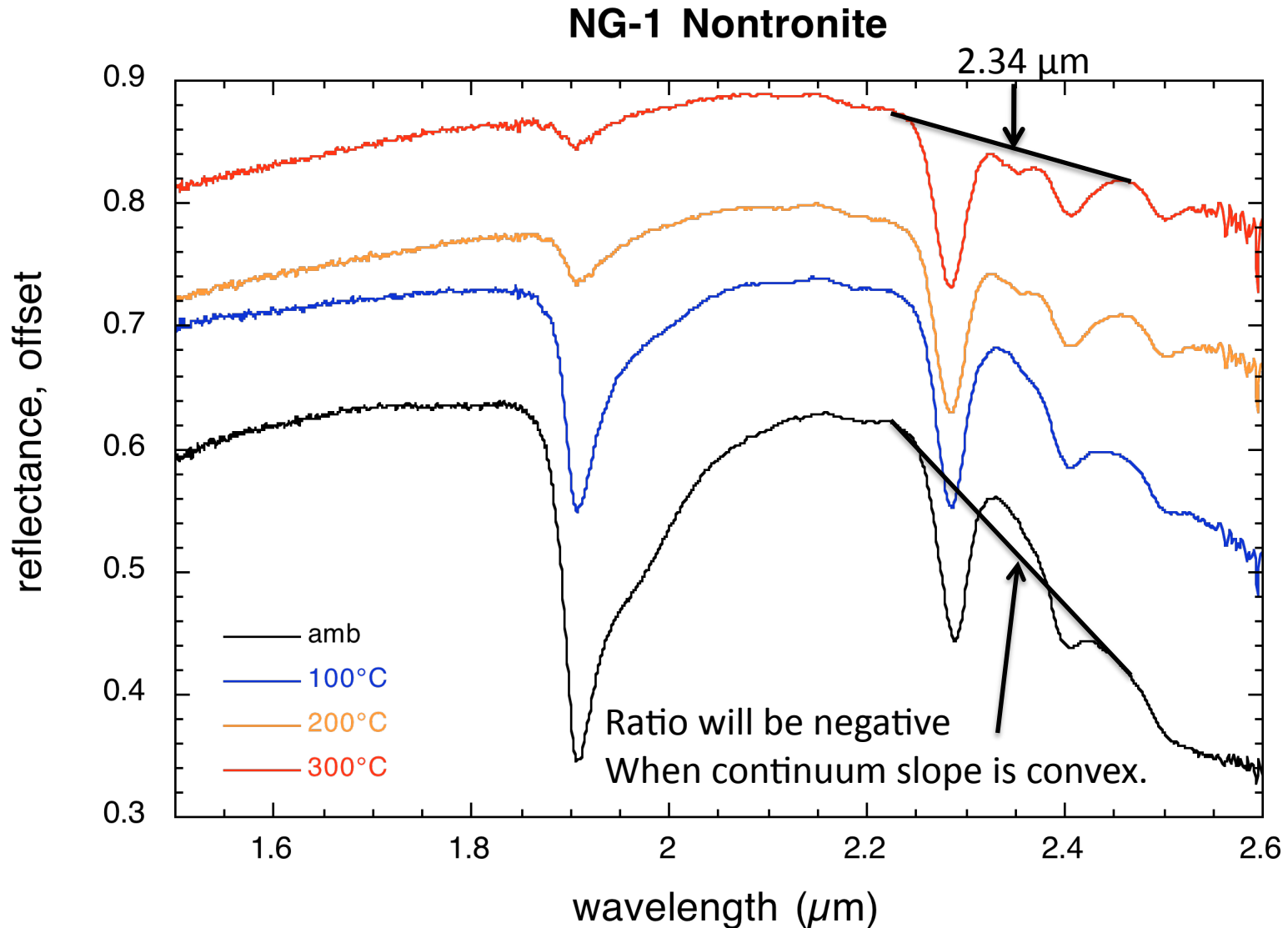
- Mg/Fe mixed-layer chlorite/smectite in delta
- Fe-bearing smectite (nontronite?); from altered olivine in Holden ejecta?
- pyroxene signatures in delta, surrounding terrains
- clay minerals in the ellipse and along any potential traverse path
- clays may be a mix of detrital and authigenic

Backup Slides

Spectral Parameters for Mixed-Layered Clays

Parameter 1: Band depth at 2.34 μm (chlorite) relative to band depth at 2.295 μm (smectite)

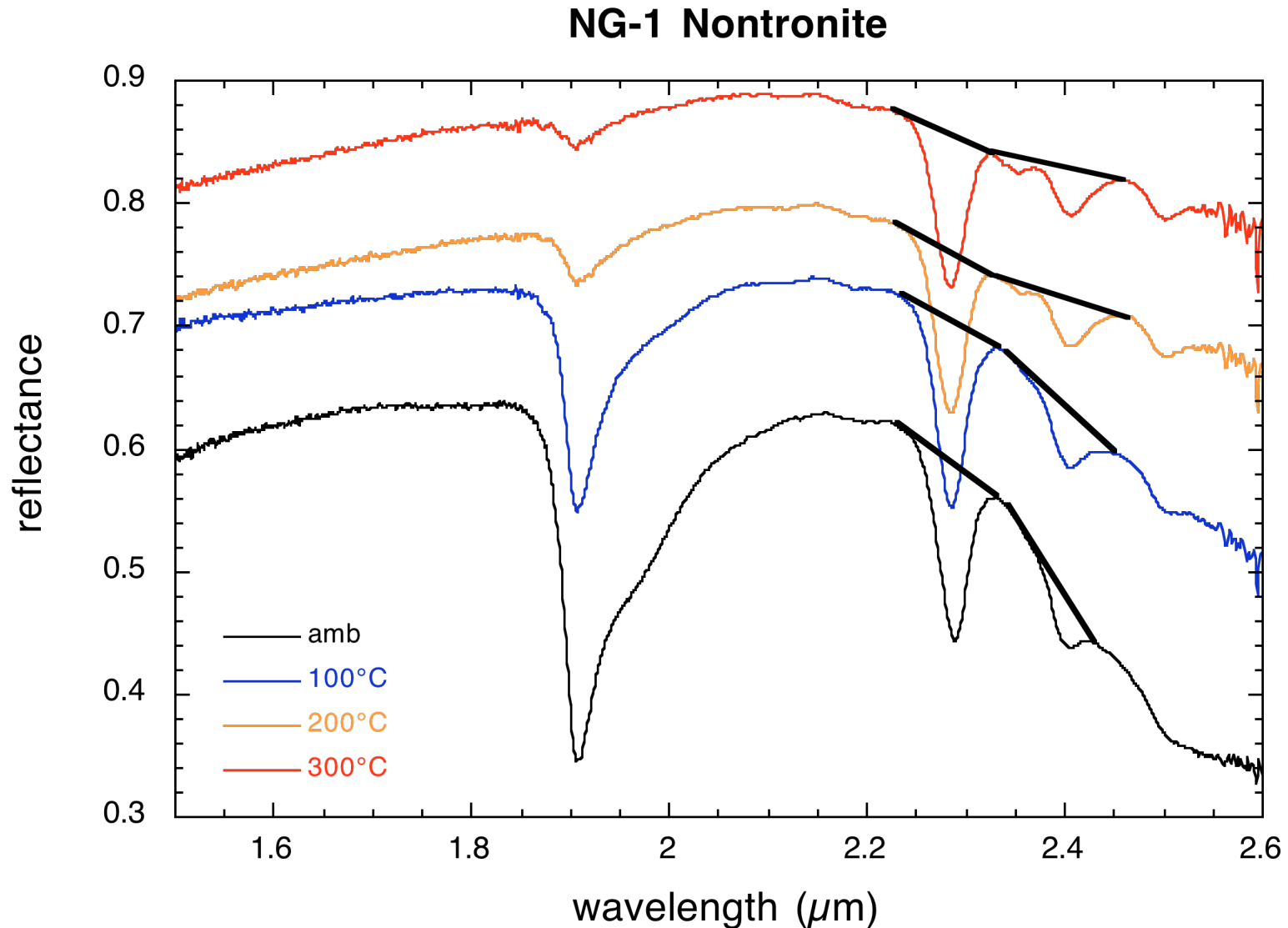
This ratio will go from 0 to 1 as the 'chlorite' band gets larger relative to the 'smectite' band.



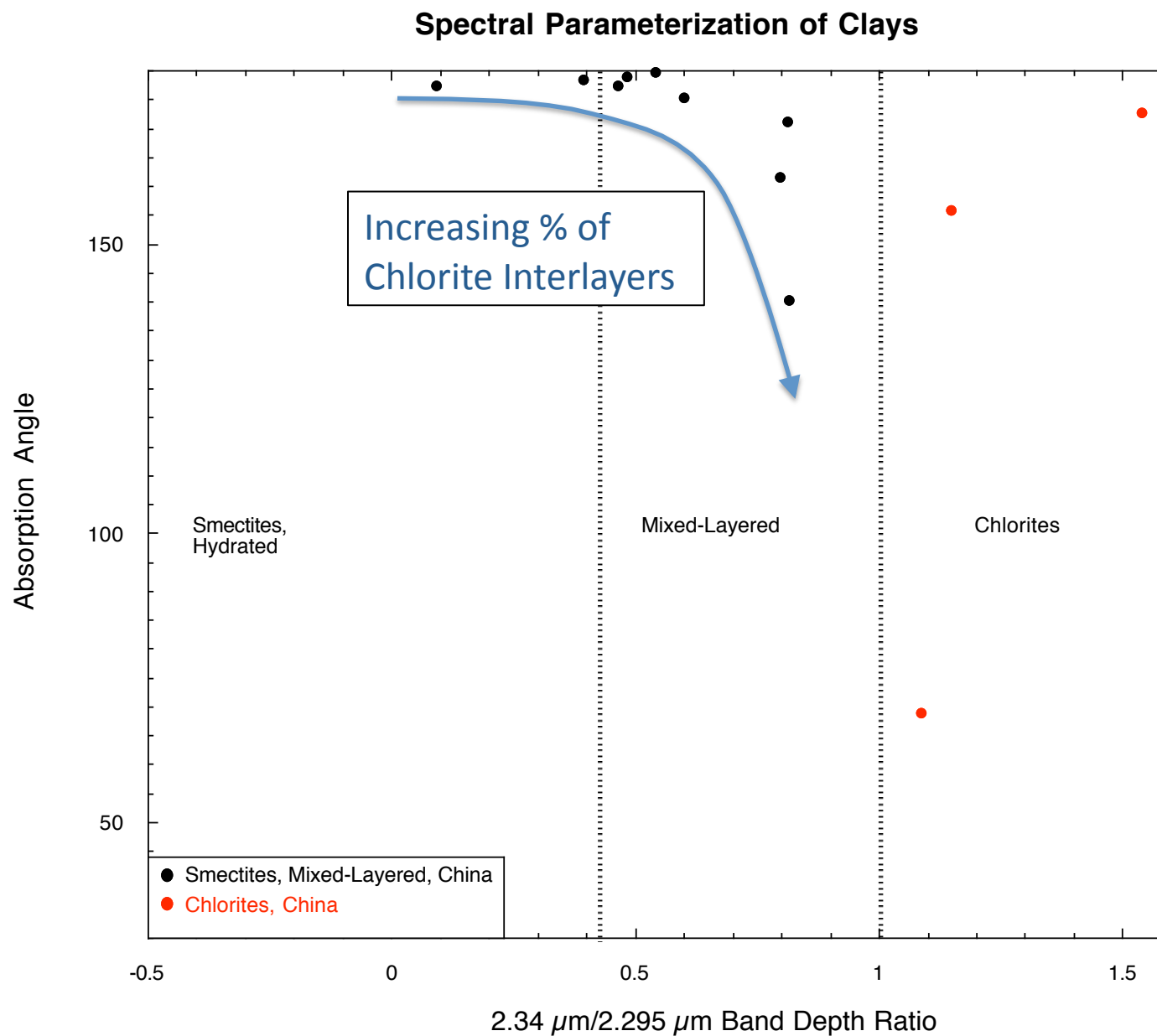
Spectral Parameters for Mixed-Layered Clays

Parameter 2: Angle between continuum lines over individual absorption bands

This angle will get smaller as the asymmetry in the 2.3 – 2.4 μm region increases.



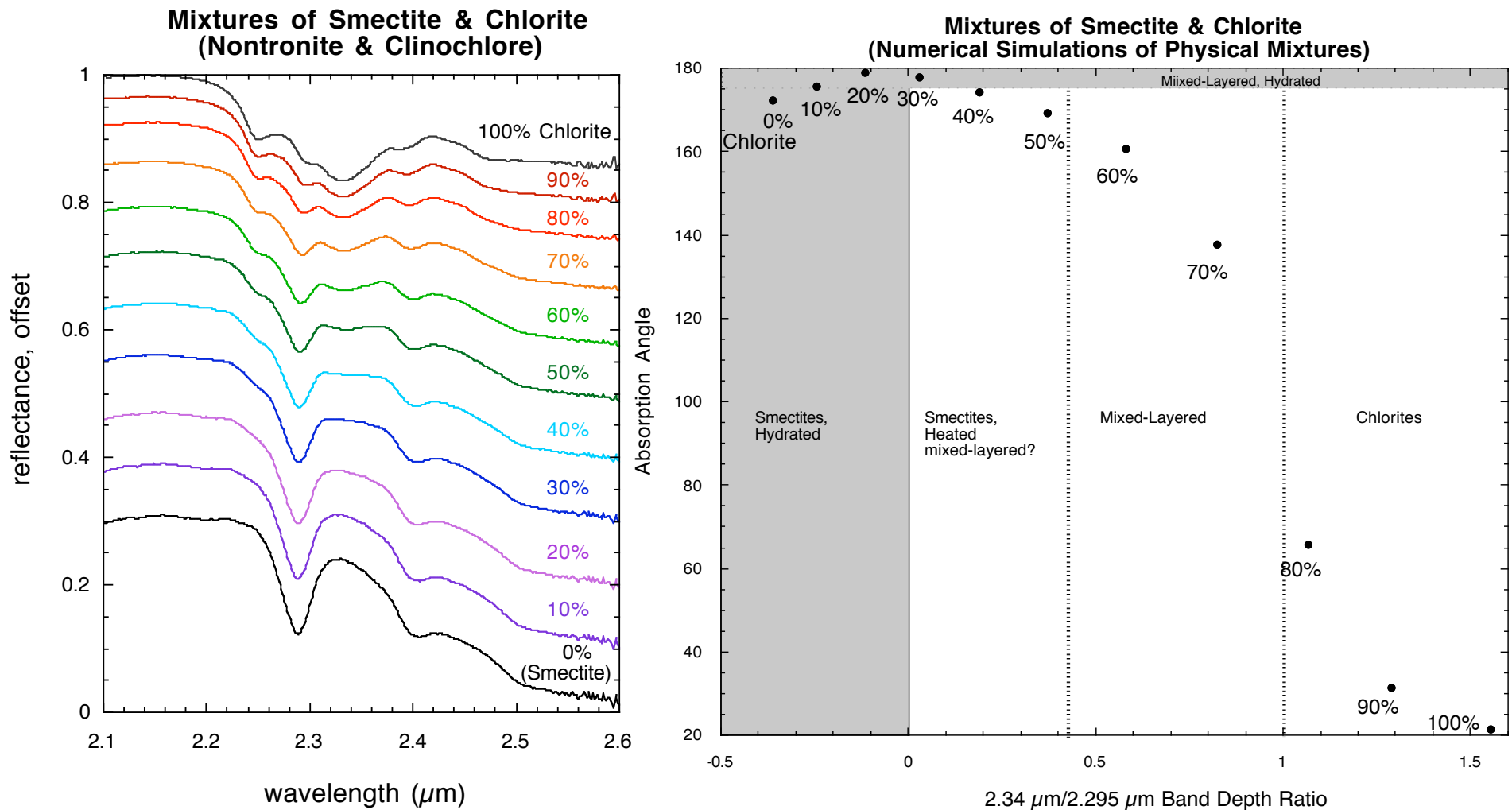
Expected Trends are Observed for the S-C/S-C Series



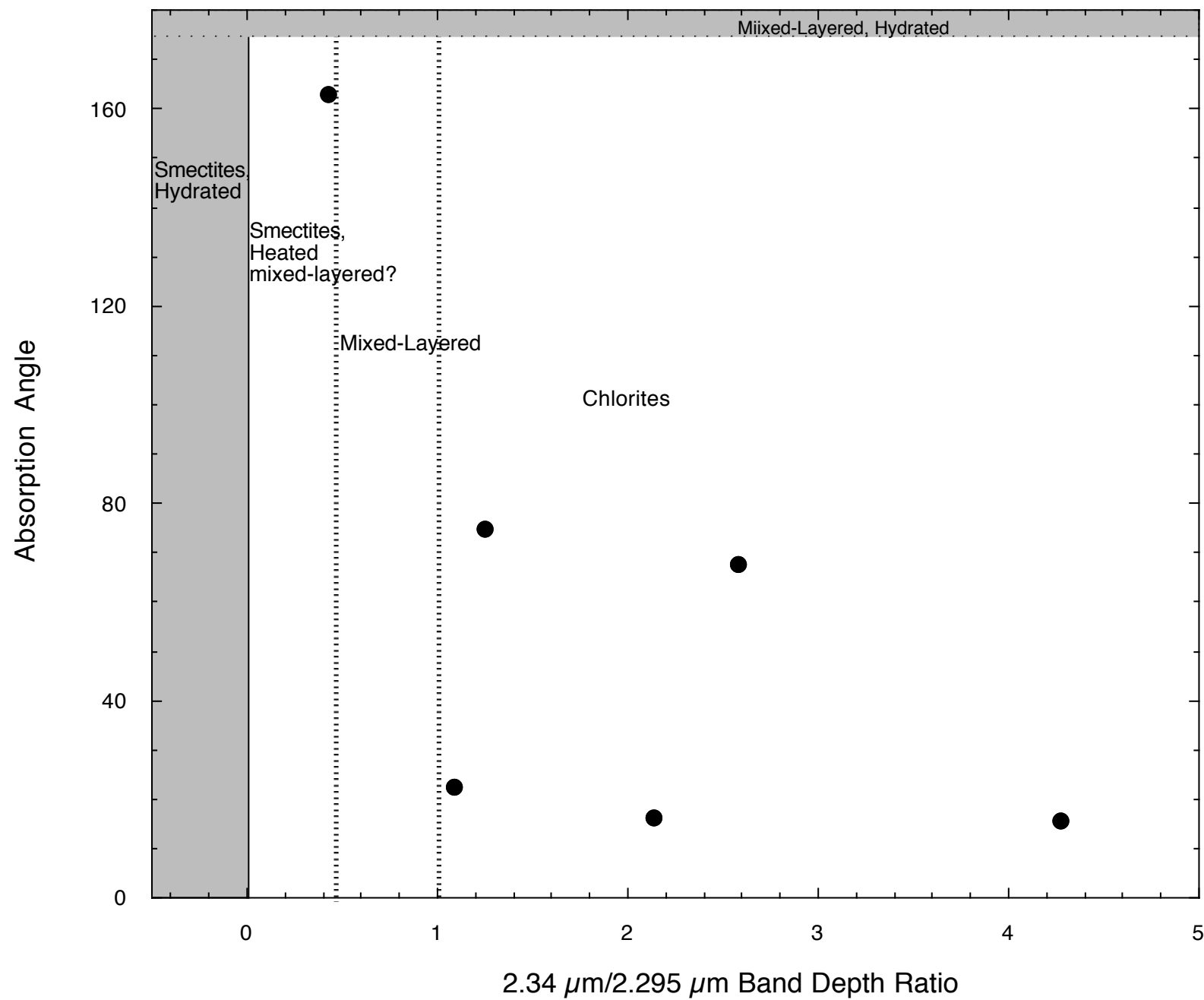
Numerical Simulations of Physical Mixtures of Smectite & Chlorite

There is some overlap in the parameter space between physical mixtures of S-C and mixed-layered S/C.

However, this is for values of 60-70% chlorite in the mixtures, and by examining their spectra it is clear that they would not be confused with smectites. *2.34 μm band increases faster than absorption angle.*

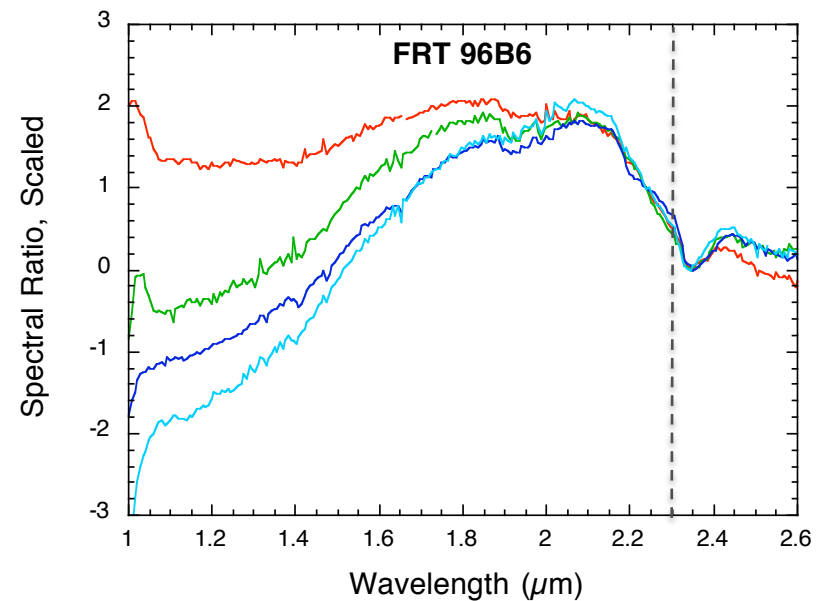
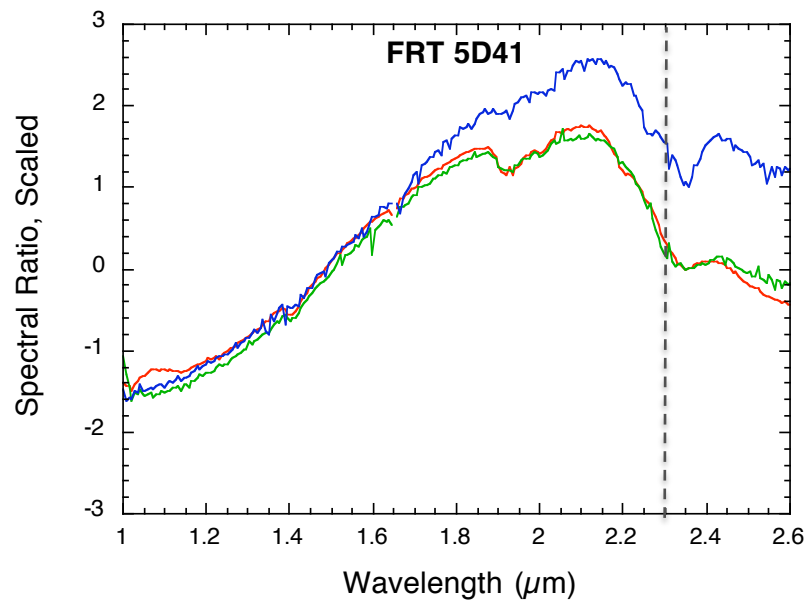
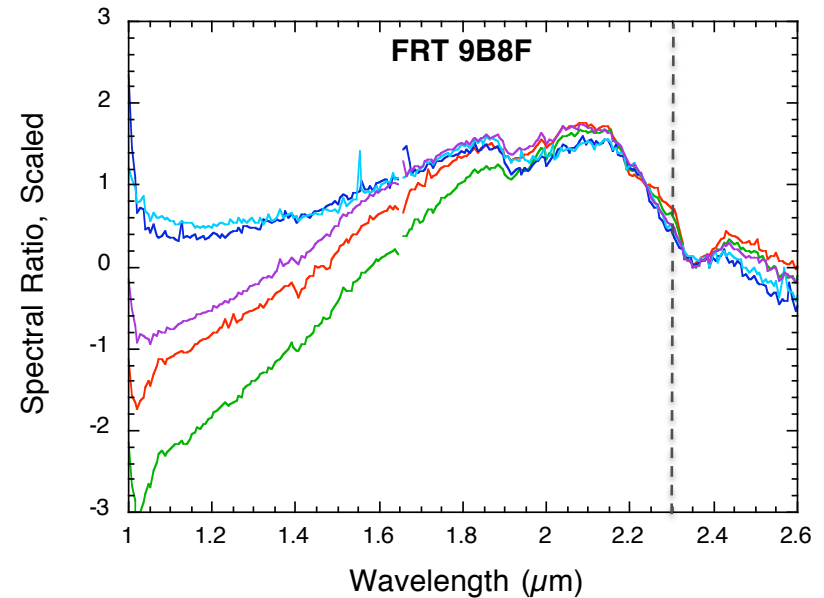
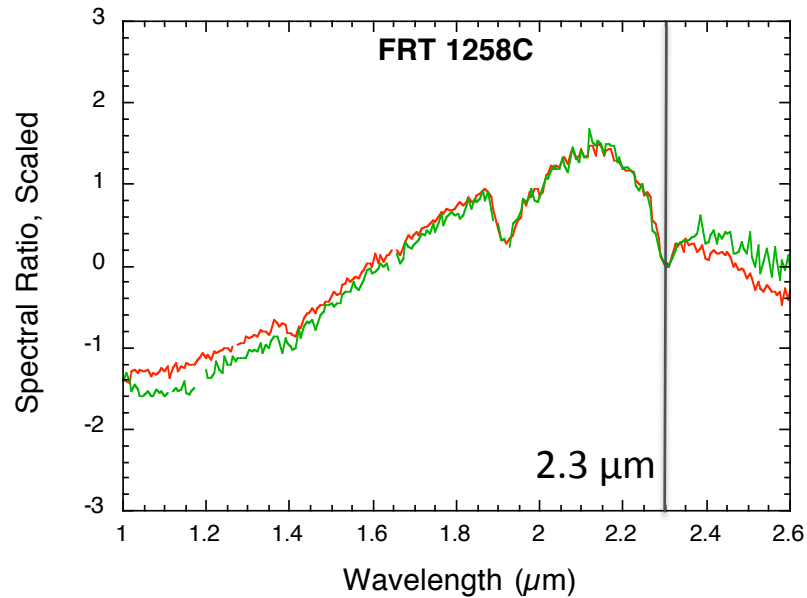


Clays in Southern Highlands (S - S/C - C Sequence)



Southern Highlands: Dominated by Mixed-Layered C/S & Chlorite?

CRISM Observations



MSL Sites: Dominantly Mixed-Layered C/S, Pure Smectite is Rare

